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THE COASTAL GEOMORPHOLOGY, SEDIMENTOLOGY AND PROCESSES OF EASTERN MELVILLE AND WESTERN BYAM MARTIN ISLANDS, CANADIAN ARCTIC ARCHIPELAGO

PATRICK McLAREN

Canada

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Preface

The studies leading to this report were undertaken in 1973 and 1974 in the general area of a proposed pipeline crossing from Melville Island where there are known hydrocarbon resources to Byam Martin Island.

In this report the author describes how the present coastline was formed and the geomorphology and sedimentology of each coastal environment including the nearshore zone. The effects of mobile ice that may impinge on the nearshore zone and gouge the bottom are explained and a useful terminology for the features produced is introduced.

From this study it is apparent that moving sea ice acting on nearshore and beach sediments is a dominant process responsible for the physiography of several coastal environments and thus this factor will be a major element in the design and construction of inter-island pipelines and coastal facilities in this part of the Svedrup Basin.

R.A. Price
Director General
Geological Survey of Canada

OTTAWA, June 1982

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THE COASTAL GEOMORPHOLOGY, SEDIMENTOLOGY AND PROCESSES OF EASTERN MELVILLE AND WESTERN BYAM MARTIN ISLANDS, CANADIAN ARCTIC ARCHIPELAGO

Abstract

The coasts of eastern Melville and western Byam Martin Islands have emerged approximately 100 m during the Holocene and are still undergoing isostatic recovery at the rate of approximately 0.35 cm/year. During deglaciation, glacial-marine sediments consisting of 33% sand, 45% silt and 22% clay with variable amounts of gravel and larger sized material reflecting local lithologies were deposited in Byam Channel. SCUBA observations show that there is little present sedimentation on the sand-silt-clay facies but grounding ice blocks result in considerable sediment reworking. Ice keels impinging on the substrate leave long linear scour tracks approximately 2 m deep which are flanked on either side by embankments 1 m high. The ice scour tracks are terminated by a crater which is surrounded by an embankment composed of excavated substrate. On rocky bottoms, where the sand-silt-clay facies is absent, ice scour features contain boulders that are freshly torn from the underlying bedrock.

During emergence, three principal coastal types were formed: deltas, sandflats and raised beaches. The deltas are of the "Gilbert" type consisting of steeply dipping (>10°) foreset beds composed predominantly of sand. Nearshore under-ice tidal currents transport this sand to adjacent coastal areas and it accumulates at the sandflat coast. The mobile sand forms a shallow sandy facies overlying the glacial-marine sand-silt-clay facies and extends from the shoreline to approximately the 7 m isobath.

Where the shallow sandy facies is thin (<3 m), ice scouring can be sufficiently deep to excavate the underlying sand-silt-clay facies and the resultant ice push deposits containing gravel and larger sized clasts can be added to the beach. Subsequent wave action concentrates the gravel by winnowing away fines and a predominantly gravel beach is formed. The addition of gravel by ice to the beach combined with emergence produces a raised beach coastline. Where the shallow sandy facies is thick (>3 m), the sand acts as a buffer against ice scouring and the gravel content of the sand-silt-clay facies cannot be added to the beach. As the shallow sandy facies emerges a sandflat coastline is formed.

Résumé

Les côtes de l'est de l'île Melville et l'ouest de l'île Byam Martin ont émergé d'environ 100 m pendant l'Holocène, et subissent encore les effets du soulèvement isostatique, au rythme approximatif de 0,35 cm/an. Pendant la déglaciation, des sédiments glacio-marins composés de 33% de sable, 45% de silt et 22% d'argile, ainsi que des quantités variables de gravier et de matériel plus gros reflétant les lithologies locales se sont déposés dans le détroit de Byam. Les observations effectuées en plongée autonome démontrent qu'actuellement, la sédimentation est réduite dans le faciès sableux-silteux-argileux, mais que des blocs de glace remanient considérablement les sédiments par affouillement. Les quilles de glace qui râclent le substrat y laissent de longues traînées linéaires d'environ 2 m de profondeur bordées de chaque côté par des levées de 1 m de haut. Ces sillons se terminent par un cratère entouré d'une levée circulaire formée de matériaux arrachés au substrat. Sur les fonds rocheux, où le faciès sableux-silteux-argileux est absent, les structures résultant de l'affouillement du sol contiennent des blocs récemment arrachés au socle.

Pendant la phase d'émersion, se sont constitués trois principaux types de côtes: des deltas, des veys sableux et des plages soulevées. Les deltas sont du type dit "de Gilbert", et consistent en couches frontales de fort pendage (>10°) principalement composées de sable. Les courants de marée littoraux, sous-glaciaires, transportent ce sable jusque sur les côtes adjacentes; il s'accumule ainsi sur des veys sableux. Les sables en mouvement forment un faciès sableux peu profond qui recouvre le faciès glacio-marin sableux-silteux-argileux, et s'étendent approximativement de la ligne de rivage à l'isobathe de 7 m.

Là où le faciès sableux peu profond est mince (<3 m), l'affouillement par la glace est assez important pour révéler le faciès sous-jacent sableux-silteux-argileux, et les matériaux ainsi arrachés puis déposés par les poussées de gel, qui contiennent des graviers et des clastes de plus grande taille, peuvent s'accumuler sur les plages. Ensuite, l'action des vagues concentre les graviers en éliminant les particules fines; il se forme ainsi principalement une grève. L'émersion du littoral, en même temps que l'apport de graviers par les glaces sur celui-ci, donnent naissance à des plages soulevées. Là où le faciès sableux est épais, le sable atténue l'effet d'affouillement par les glaces, et les graviers que contient le faciès sableux-silteux-argileux ne peuvent aboutir sur les plages. À mesure qu'émerge le faciès sableux peu profond, il se forme une côte à veys.

INTRODUCTION

Purpose

This study, undertaken during 1973 and 1974 was in response to increasing exploration for, and discovery of, oil and gas in the Sverdrup Basin of the Queen Elizabeth Islands (Fig. 1). Knowledge of coastal physiography and processes was required to assess possible methods of transporting hydrocarbons by either inter-island pipeline or ice-strengthened tankers from the north to southern markets. This study concentrated on the coasts of Byam Channel (Fig. 1), the first of the many proposed pipeline channel crossings.

The purposes of this report are to (i) describe the elements of the physical environment that have resulted in the existing coastal physiography, (ii) describe the geomorphology and sedimentology of each coastal environment including the nearshore zone, (iii) explain the effects of mobile ice that impinge on and gouge the nearshore bottom environments, (iv) suggest a terminology for the features produced by grounding ice and (v) show that, for this area, ice movement acting on nearshore and beach sediments is a dominant process responsible for the physiography of several coastal environments.

Location and Accessibility of Study Area

The study examined 180 km of the east coast of Melville Island and 59 km of the west coast of Byam Martin Island (Fig. 1). Both coasts lie between 74°56'N and 76°04'N latitude and 104°14'W and 107°17'W longitude. The area is covered on the Canadian National Topographical Series map sheets 78 H, E (Byam Channel) and 79 A (Domett Point). The most recent airphoto coverage of the coastal region, obtained in 1959, is at a scale of 1:60 000.

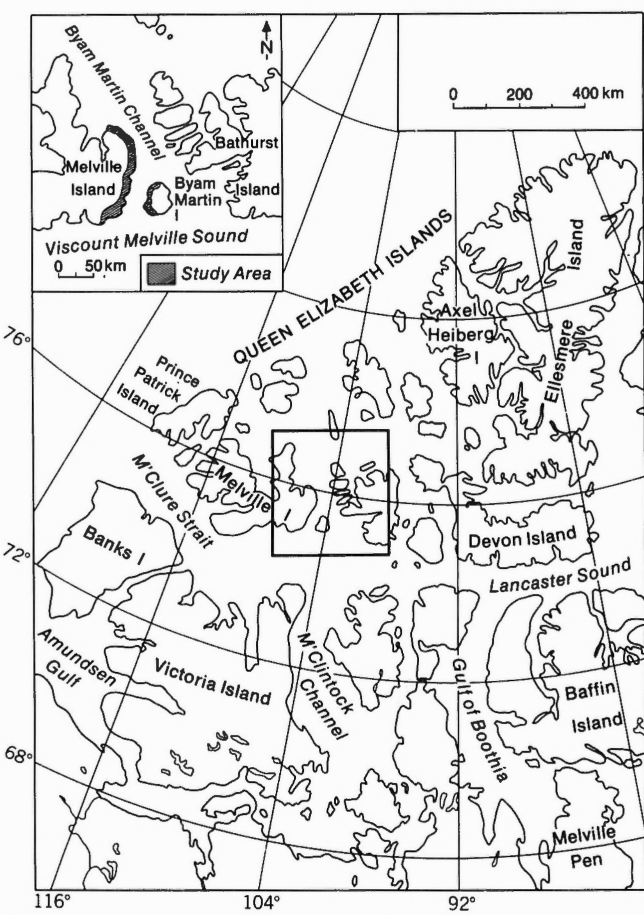


Figure 1. Arctic archipelago and location of study area.

The area can be reached by aircraft throughout the year and by ship from late August to the end of September. A major petroleum company base at Rea Point (Fig. 2) on the east coast of Melville Island is serviced by an air strip large enough to handle jet aircraft. Privately owned company planes fly regularly from Edmonton to Rea Point all year long and a sealift operates during the short open water season.

The nature of the coast allows light aircraft (Twin Otter and smaller) to land almost anywhere. A Jet Ranger 206 helicopter operated safely on skids until early July, landing both on the sea ice and on shore. After this date increasing open water areas in Byam Channel necessitated the use of floats. Logistic support can be maintained from Resolute Bay, the nearest settlement, approximately 300 km to the east of Melville Island.

Previous Work

The earliest coastal observations in arctic environments are found in the accounts of the 19th and early 20th century explorers. Their reports are perhaps the only source for detailed and continuous descriptions of winter ice conditions, breakup, summer ice conditions and freezeup over periods of up to several years. They provide valuable insights into the timing and magnitudes of arctic processes.

Sir Edward Parry who discovered and named both Melville and Byam Martin islands in 1819, carried with him Alexander Fisher, an assistant surgeon who made one of the earliest observations of an arctic beach. "The beach did not

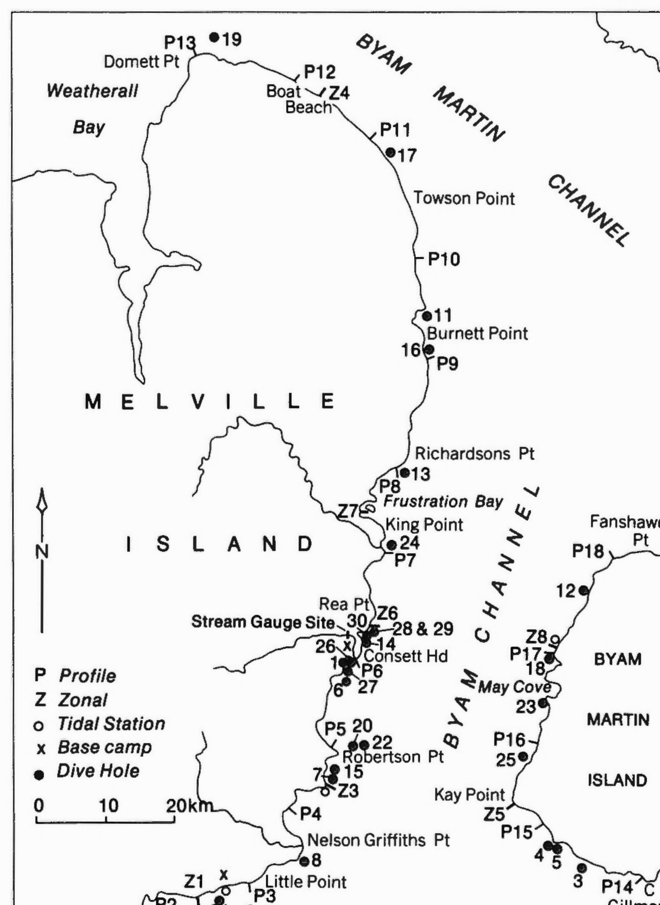


Figure 2. Locations of place names and work activities referred to in text.

appear to be much beaten by the sea, for the rocks and loose stones that composed it did not bear the marks of much attrition. This may, in a great measure be attributed to the manner in which it is guarded by ice, for all along shore there was a chain of large pieces of it from eight to ten feet thick, which of course shielded all within it from the violence of the sea, that is to say, if such ever exist" (Fisher, 1821).

Other notable explorations of the area were involved with the search for the missing expedition of Sir John Franklin which left England in 1845 and never returned. These include the voyages of McClintock and Bradford (1851), Belcher (1852-1854) and Kellet (1852-1854). Numerous journals exist by various members of these expeditions, many of which contain illuminating information on the physical environment of the Melville Island region. Summaries of the geographical exploration of the region are contained in Taylor (1955) and Tozer and Thorsteinsson (1964).

In the early 20th century, three voyages were made through the Arctic by Captain J.E. Bernier primarily to establish Canadian sovereignty. Bernier had on board his ship, the "Arctic", J.G. McMillan who was the first official geologist on a northern expedition. In his report, special effort was made to incorporate all observations of the early explorers relating to physical and geological features in the archipelago (McMillan, 1910). The following is his description of spring melt in the nearshore of Winter Harbour.

"In considering the conditions along shore, it will be readily seen that where ice forms to a depth of 8 feet, all of a less thickness will have firmly attached to the bottom as the thickness increases. The ice not so attached is free to move up and down with the tide. This leads to the formation of a series of cracks parallel to the shoreline, the last of which follows the line of 8 feet depth. When the ravines begin to discharge in the summer, immense volumes of water, heavily laden with sediment, flow over this firmly attached shore ice, and make their way through these cracks into the sea. The result is that the top is rapidly melted away and the bottom covered by each flood tide and left bare by the ebb. The finer sediment which is carried beneath the floating ice is, on the other hand, at all times, subject to the action of the currents. The difference in conditions is manifested by a sudden deepening at this point. From time to time after the middle of July, masses of this shore ice become detached from the bottom, and floating to the surface are carried about by the wind and rapidly melted away. It is likely, however, that some portions of this ice, instead of being so removed, remain covered in the position in which they were formed, and aid in the shoaling of the shore waters. At Cape Providence ice was seen, still firmly attached to the bottom, in the latter part of August".

Vilhjalmur Stefansson essentially completed exploration of the western Queen Elizabeth Islands from 1913-1918. Unlike all before him, Stefansson travelled by dog team, thus becoming perhaps even more intimately acquainted with the physical properties of the polar pack ice. "The Friendly Arctic" (Stefansson, 1921), although written from an autobiographic rather than a scientific viewpoint, contains much pertinent information on the type and scale of arctic processes. There is a vivid account of the formation of pressure ridges and a description of the effects of a gale lifting landfast ice from the nearshore bottom and widely distributing coastal sediments.

In attempts to classify coasts, the arctic has been included in several schemes proposed by Valentin (1952), McGill (1958), Bird (1967) and Taylor (1973). Most pertinent to the coasts of Byam Channel is the information provided by McGill whose map indicates that the east coast of Melville Island has undergone extensive post-Wisconsin marine submergence with subsequent emergence caused by isostatic rebound. It is within the limits of both permafrost and pack ice and has a tide range of less than 10 feet. Furthermore, it is classified as a "lowland, destructional, complex plain" which has been glaciated. This is a remarkable amount of useful information to put on a world map at a scale of 1:25 000 000 and the present study has shown that essentially all the above information is correct with the exception of the term "destructional".

The most recent synthesis of arctic coastal characteristics is by Taylor (1973). Concerned principally with the Queen Elizabeth Islands, he uses (i) general morphology and coastal relief (ii) tidal conditions and (iii) length of open water season to produce a physical framework for the coasts. These criteria are used to make three separate classifications. The east coast of Melville Island falls in a "ridge and valley" coastal type (i.e. the coastal configuration is dependent on bedrock structure). The coast also is in a microtidal (<2.13 m) environment with an ice category defined as "enclosed" (i.e. there is less than four weeks of restricted ice movement in the channels).

Early workers in polar coastal environments regarded ice primarily as an inhibitor of 'normal' processes found in lower latitudes. Sea ice can inhibit wave action for many months of the year and Horn (1967), after examining beaches in the Sverdrup Islands northeast of Melville Island, suggested that the amount of time waves can act on a beach should be measured in days rather than weeks. Even after breakup, individual ice pans rapidly cause waves to lose their energy (Shapiro and Simpson, 1953). Ice shoaling in nearshore shallow water can form ice fences (Glukhova, 1964; R.A. Davis, 1973) which prevent waves and longshore currents from acting upon the beach and nearshore zone.

The development of an ice foot which is the ice formation joining the land and sea between high and low water marks (Joyce, 1950) also protects the beach against wave processes. Numerous authors have written about the role of the ice foot in the arctic beach environment (e.g. Feyling-Hanssen, 1953; Rex, 1964; Short and Wiseman, 1974). Five kinds were described by Wright and Priestly (1922) to which Joyce (1950) added two more. McCann and Carlisle (1972) contains a good discussion and a detailed review of the literature on the subject.

There is some controversy on the erosive power of the ice foot. Owens and McCann (1970), McCann (1972) and Taylor and McCann (1976) have stressed the protective role of the ice foot against wave processes. Earlier workers, however, suggested that freeze-thaw action during the formation of the ice foot, if the ice is forming on rock, has enormous erosive power (Feyling-Hanssen, 1953). Joyce (1950) considered the ice foot in the Antarctic an important agent of erosion, because when it breaks up it rafts away large quantities of beach material on its undersurface. Rex (1964) indicated that an ice foot can also be responsible for beach sedimentation. He defined a gravel-sand ice foot (a storm ice-foot of Wright and Priestly, 1922; or a "Kaimoo" of Moore, 1966) which is a finely bedded ice-cemented conglomerate mantling the beach. It thaws in place without breaking away from shore allowing the sand and gravel to be added to the beach surface. Clearly there are different types of ice foot which have varying effects on the beach.

The action of ice on the beach produces numerous unique features. Many have been described by Nichols (1961), who listed characteristics of beaches formed in polar climates. Ice push ridges are one of the more important features and have been described in some detail by Nichols (1953), MacCarthy (1953), Rex (1964), Hume and Schalk (1964, 1976), Greene (1970), Owens and McCann (1970) and Taylor and McCann (1976). In general, such deposits have been regarded as interesting though minor phenomena confined to polar beaches. For example, Hume and Schalk (1964) attempted to obtain exact measurements of the size and quantity of deposits left by ice push along the coast near Barrow, Alaska. They suggested that up to 10 per cent of the total mass of beach sediment above sea level was the result of the addition of sediment by ice push. They concluded that more typical figures would be 1 to 2 per cent. They also estimated that approximately 5 per cent of the Alaskan coast above the Arctic Circle is attacked by ice during any one year. If their figures are extrapolated, in 20 years the whole coast theoretically, may have had up to 10 per cent more beach material added. Suppose only an average of 3 per cent new ice push material is considered; this would result in 100 per cent more beach sediment being added to the whole coast in only 667 years. In spite of this, Hume and Schalk leave the impression that ice push is not an important process.

A special type of ice push ridge has been defined as a boulder barricade or shoreline rampart (Ward, 1959; Nichols, 1953; Goldthwait, 1957; Bird, 1967). In addition, a large number of relatively minor features of polar beaches have been described. These include ice mounds (Owens and McCann, 1970), pitted beaches (Nichols, 1961) kettles (Dionne and Laverdière, 1972) and microfluvial deposits (Greene, 1970).

The presence of permafrost is also a unique characteristic of arctic beaches. Rex (1964) has used the term frost table to define the upper surface of the frozen portion of the active layer. For the Barrow area, Rex suggested that the depth to the frost table is sufficient to have little effect on the beach stability. Both McLaren et al. (1975) and McDonald et al. (1973) found that the frost table plunged rapidly in the intertidal zone and nearshore. Owens and McCann (1970) and McCann and Hannell (1971), on the other hand, concluded the opposite for Devon Island beaches. They suggested that the frost table extends well into the intertidal zone and can prevent reworking of large amounts of beach material, either by ice push or by storm wave action.

In contrast to the seemingly unimportant role of ice on the beach, numerous workers (e.g. Carsola, 1954; Rex, 1955; Weber, 1958) have realized that grounding ice can cause considerable disturbance and modification to sea and lake bottom sediments. With the advent of side-scan sonar, the effects of mobile ice scraping and gouging bottom sediments have been widely studied, particularly on the Beaufort Sea Shelf, in response to offshore drilling hazards (Pelletier and Shearer, 1972; Reimnitz et al., 1972, 1973, 1974; Barnes and Reimnitz, 1974; Lewis, 1978, 1979). The influence of ice gouging the seafloor on sedimentary environments has been reported by McLaren (1975), and Toimil and Grantz (1976). Reimnitz et al. (1977) have suggested large shoals in the Beaufort Sea are migrating shoreward due to ice-related processes.

Iceberg scouring, both relict and recent, has been reported in the northeast Atlantic (Belderson et al., 1973), the Norwegian Trough (Belderson and Wilson, 1973), the Labrador Sea (Van der Linden et al., 1976), and the Newfoundland continental shelf (Harris and Jollymore, 1974; King, 1976). Kovacs and Mellor (1974) and Chari and Allen (1972, 1973, 1974) have attempted analyses of the forces required for ice to scour the bottom.

Field Methods

Field work was carried out from June 13 to August 30, 1973, and from June 1 to August 12, 1974. The first summer followed, in part, the "zonal method" of coastal reconnaissance outlined by Hayes et al. (1973). This method was devised to enable a rapid determination of regional patterns of morphology and sedimentation over relatively large (up to 600 km) stretches of coastline. The following summarizes the zonal method and its application in the present study.

1. A single large physiographic unit is chosen as the region of study. The coasts of eastern Melville and western Byam Martin Islands are primarily uplifted and prograding and show no major physiographic divisions.
2. Study of aerial photographs, maps, charts and available literature of the chosen area is completed prior to field work.
3. Aerial reconnaissance of the entire area precedes ground work during which the coast is photographed. As ice conditions changed throughout the field season a photographic record of the coast was taken as often as possible. Complete photographic inventories of the coastline were made with a 35 mm camera on June 22, July 11, and August 13, 1973. The photos were oblique and taken at altitudes varying from 120 to 300 m. In 1974 such extensive photographic coverage was not continued.
4. After initial reconnaissance of the area a sediment sampling interval is chosen. In this study a set of 19 profiles (P0 to P18, Fig. 2) were established at approximately 16 km intervals. Each profile was surveyed with a Zeiss Ni-2 level. The elevation was taken approximately every 6 m and at intervening topographic inflections or facies changes.

Each facies encountered on a profile was sampled by pushing a short plastic core tube into the top 15 to 20 cm of sediment. At each point measured on the surface profile, a hand auger was used to determine the depth to the permafrost (or frost table, Owens and McCann, 1970). The depth was measured to the nearest centimetre. Thus, both changes in the beach profile and frost table profile could be monitored through time. All profiles were resurveyed two or three times during the summer of 1973 and once during the summer of 1974. Several were also reprofiled in October 1973, during winter conditions.

At every profile, handheld vertical photographs were taken of each sample location, and trenches were dug to either the depth of the frost table or to the water table in order to examine the relationships among different facies. Ground and air photographs recorded the ice conditions within the profile location area. Two, eight foot T-bar fence posts driven into permafrost as deeply as possible served as permanent benchmarks and to mark the profile location.

5. In addition to the two-dimensional framework provided by the profiles, specific sites, called "zonals", thought to be representative of particular coastal types are chosen for detailed study. Eight zonals (Z_1 to Z_8, Fig. 2) were selected in the study area and the following information was obtained at each one.

(a) Three profiles were located approximately 100 m apart. All the above techniques listed in (4) were repeated for these profiles with the addition of a sample collection from every surveyed point on the profile.

(b) The complete area contained within the profiles was mapped using a Wild RDS tacheometer. The elevations in the zonal were first taken on a grid system (approximately every 12 m). Geological features were then mapped separately and superimposed on the grid. All elevations were used in constructing a three-dimensional block diagram of the zonal. A standard computer contour plot program greatly facilitated the initial construction of the zonal maps.

During the 1973 field season tide data were obtained at four locations (Fig. 2). The tide gauge, a Foxboro circular recorder, consisted of a simple pressure head mounted several feet below low tide level and connected to the recorder by a flexible capillary tube. Unfortunately ice movements and interference by polar bears limited observations to a few days at a time.

Observations in 1973 led to the realization of the important role of grounded nearshore ice on the coastal environments. In a related program, Taylor (1974) used with limited success conventional remote sensing techniques of echo sounding, sub-bottom profiling and side-scan sonar. In his discussion Taylor concluded: "Nearshore research using a small open craft (19 foot pneumatic boat powered with a 40 horsepower motor) is very dependent on weather and local sea ice conditions. The work is further hampered by the short open water season which occurs along the Melville Island coast. Even in seasons with early ice breakup as in 1973, pieces of mobile ice continue to shift back and forth along the shoreline." Consequently, extensive boat work was inhibited and detailed surveys were limited to the bay at Z_7 (Fig. 2) and a single traverse from Z_7 south to Rea Point (Taylor, 1976).

Accordingly, a program of nearshore study using SCUBA, was conceived and implemented for 1974. The advantages of this technique were: (i) dives could take place through cracks, seal holes and strudels (holes through which meltwater drains, Reimnitz et al., 1974) before ice breakup. Thus, observations could be made without using a boat and were not as dependent on favourable ice and weather conditions; (ii) diving enabled direct observation of the bottom and the adoption of a sampling procedure which allowed the geologist to decide where samples would be most valuable; (iii) the geologist had the ability to photograph interesting features, take samples in an undisturbed state for structural and micropaleontological analyses and collect engineering data from in situ sediments.

Disadvantages of SCUBA include: (i) it does not have the range that remote sensing techniques operated from a ship can provide; (ii) the location of dives is dependent on finding entry into the water and thus a systematic observation and sampling program can not be initiated. For this reason the dive locations (Fig. 2) are random and numbered in the order that they were made. Unfortunately, it was not possible to locate dives with respect to selected onshore profiles or zonals; (iii) it is relatively dangerous, particularly for a beginner.

A total of 93 dives, making up 50 underwater hours, were successfully completed. Observations were taken in water depths ranging from 3 to 25 m and were within 4 km from shore. Whenever possible dives were made within swimming distance of grounded ice blocks and samples taken within and outside ice scour tracks. McLaren and Frobel (1975) discuss in detail under-ice SCUBA and geological techniques with the purpose of providing some of the experience gained during this program.

Acknowledgments

The author is indebted to numerous agencies and individuals who have assisted this study in both major and minor ways. Special thanks are given to M.O. Hayes of the University of South Carolina who supervised the project for the author's Ph.D. research. Ron Coll, Bill Keenan, Ken Pugh and David Shearer ably assisted 1973 field operations. Clement Locat and Pierre De Courval, also student assistants, were invaluable for both 1973 and 1974 seasons. David Frobel and Stephen Van Haaften took part in diving operations requiring, on occasion, initiative and courage well beyond the call of duty.

Particular appreciation is given to Sid Halpern of the Department of Energy, Mines and Resources Technical Field Support Services and to Fred Alt at Polar Continental Shelf in Resolute. Both went out of their way more than once to give first class logistical support.

To the large number of individual pilots who took part in field operations, I express my thanks. Perhaps one deserves special mention, Bill Henderson, who brought several of us to earth safely after the engine had blown apart.

Critical reading of the manuscript by S.B. McCann provided helpful comments and editorial changes which were gratefully received.

PHYSICAL SETTING

General Physiography and Geology

Both coasts fall within the Parry Plateau, a division of the Innuitian Region (Bostock, 1970). The terrain is characterized by east trending ridges which are broad and flat topped. They are separated by wide, flat-floored valleys. Tozer and Thorsteinsson (1964) classified the region as ridges and plateaux developed on folded Paleozoic rocks. Locally (within the drainage basins that empty into Byam Channel), the east trending ridges are less pronounced and in spite of the dominating structure, the drainage is characteristically dendritic. There are two reasons why the drainage does not reflect the dominant structure. First, the geological formations are similar and consist predominantly of sand and siltstone. Second, within a particular formation, there are frequently varying degrees of lithification. For example, the Hecla Bay sandstone (Devonian) may form a ridge in one location and a valley floor in another.

Maximum elevation (385 m) is found in the north on a small ridge of Blue Fiord limestone (Devonian). This elevation is exceptional and the plateaux are commonly about 150 m high. Valleys are steep walled with an average relative relief of 90 m.

The geology of Melville and Byam Martin islands has been mapped by Tozer and Thorsteinsson (1964) and Kerr (1974), respectively, with modification of the former by Barnett et al. (1975). Both coastal regions consist of folded upper Devonian interbedded marine and nonmarine sandstones, siltstones and shales. Fold axes trend east-west. Approximately half of the Melville coastline consists of Hecla Bay and Weatherall formations and the remaining half is made up of Griper Bay Formation. The Hecla Bay Formation in places forms resistant bedrock headlands such as Robertson and Kay points (Fig. 3).

An outlier of horizontal Cretaceous beds rests unconformably on the folded Devonian rocks in the southeast, north of Ross Point. These consist of unlithified sandstone, siltstone and shale. The coast of Byam Martin Island is almost exclusively Griper Bay Formation with only a narrow band of Hecla Bay outcropping in the Kay Point area (Fig. 2).

The similarity of the geological formations has resulted in the lack of obviously distinct morphological units on the two coastlines, with the possible exception of the rocky headlands mentioned earlier. However, the characteristic coastal features observed on such a headland can also be observed on other bedrock types. For these reasons, and because of the aforementioned dendritic drainage pattern, the various formations are all considered as a relatively homogeneous rock type in this study.

The presence of an almost ubiquitous weathered drift containing erratics indicates that ice covered both islands during Pleistocene time (Tozer and Thorsteinsson, 1964). The lack of fresh glacial landforms, however, suggests that late Wisconsin Laurentide ice did not reach any further than the south coast of Melville Island (Fyles, 1967). Despite the apparent absence of Laurentide ice cover, the spectacular evidence of marine transgression and Holocene emergence (Fig. 4) indicates the substantial influence of nearby late

Wisconsin ice. Marine limit determinations and emergence curves derived from radiocarbon dates show that the east coast of Melville Island has undergone up to 100 m of Holocene emergence and is still recovering at the rate of about 0.35 cm/year (McLaren and Barnett, 1978).

Climate, Currents and Ice Regime

Winds

Wind data are available for Rea Point (Fig. 2) since 1972 (Environment Canada, 1972-1974). On monthly mean pressure charts, pressures are consistently low on the west coast of Greenland and higher in the area northwest of Mould Bay on Prince Patrick Island. The pressure gradient is strongest from September to May and results in average wind speeds of 20-23 km/h with a prevailing wind direction of northwest to north. The gradient is weakest during June, July and August, and although average wind speeds remain the same, the prevailing direction is random and can vary from north-northwest to south. Peak winds of over 95 km/h are common and nearly always blow from the prevailing direction. They can occur anytime during the year. Terrain also has an effect on wind direction in the Arctic Islands. The northwest orientation of Byam Martin Channel and the north orientation of Byam Channel serve to guide the prevailing winds to these dominant directions.

Currents and Tides

In Byam Channel, documentation of ice movement shows that currents are from the north, probably reflecting the prevailing wind direction (Lindsay, 1969). On entering Viscount Melville Sound, flow is divided into east and west directions. Eastward currents continue through Parry Channel. The westward flow remains close to the south shore of Melville Island before sweeping in a counter-clockwise turn to follow in an eastward direction.

In spite of the dominant north to south current in Byam Martin Channel, littoral transport directions reflected in coastal features such as spits (Fig. 5) are apparently random (Fig. 6). Local drift directions are probably dependent on sufficient fetch being made available by favourable ice conditions during a relatively short period of time. Probably the spits represent catastrophic storm events since fetch conditions can never remain stable for very long.

Diving observations indicated that currents were either small or nonexistent. Most often currents estimated at 10-15 cm/s were felt under the ice in shallow water less than 4 m (DH4, DH16, Fig. 2). They were invariably parallel to shore and their direction coincided with ebb and flood tide. Occasionally ripple marks were observed in fine sand indicating that these currents were able to attain 30-40 cm/s (Southard, 1971). In deeper dives currents were rarely felt except on August 5, 1974, at DH22 (Fig. 2) where tidal currents were estimated at 50 cm/s.

Tide data from Z_2, Little Point, Z_3 and Z_8 (Fig. 2) indicate a semidiurnal tide with an amplitude that decreases steadily from Viscount Melville Sound, north into Byam Channel. Maximum tides measured from south to north at the four stations were 1.2, 1.1, 0.98 and 0.76 m respectively. The tide appeared to be simultaneous over the area.

Currents attributable to tides were measured at a water depth of 107 m in the middle of Byam Channel. Maximum velocities ranged from 20 cm/s to 46 cm/s and tended to increase with depth. Although direction measurements were meaningless due to the proximity of the North Magnetic Pole, the variation in the successive values of velocity showed an irregular but semidiurnal pattern (Polar Gas, personal communication).

Temperature, Ice Thickness and Precipitation

Mean daily temperatures (Fig. 7) are based on data from the Rea Point meteorological station (Environment Canada, 1969-1974). July and August are the only months where the mean goes above freezing and July is the hottest month with a mean of 4.4°C. Temperatures drop rapidly to a minimum low of -35.6°C in February.

Superimposed on the temperature curve (Fig. 7) is a generalized average ice thickness curve for the Queen Elizabeth Islands (Lindsay, 1969). The two curves indicate a time lag between minimum air temperature and maximum ice thickness. The generalized maximum ice thickness of 2.08 m agrees well with research on the ice thickness in Byam Martin Channel during the spring of 1973 (Polar Gas, personal communication). The curve suggests that no ice exists between the third week in July and the second week in August. However, during this time there will be a varying concentrations of mobile ice.

Total monthly precipitation (Fig. 7) increases directly with temperature and the amount of open water. The average yearly total, however, is only 9.1 cm which classifies the region as a desert (American Geological Institute, 1977).

Ice Regime and Pattern of Breakup and Freezeup

During winter in Byam Martin Channel, the sea is covered with approximately 80 per cent old ice, although there are increasing percentages of first year ice southwards into Byam Channel. The ice thickness curve (Fig. 7) shows continuous ice cover over the region for at least nine months of the year. During this time the inter-island ice is shorefast and no major movement takes place (Swithinbank, 1960). Breakup usually occurs in July though variations from season to season are too large to determine a more precise date. Significant ice movement is confined to August and September with some motion during storms in October and possibly November.

Breakup and general ice movement are controlled by winds and currents and therefore, the overall pattern proceeds each summer from the southeast to the northwest. Clearing of ice from Parry Channel develops in varying degrees each year depending on summer winds, the previous summer's breakup and to a small extent on temperature. The clearing develops as an extension of open water in northern Baffin Bay and progresses westward to 98°W between Bathurst and Prince of Wales islands. Farther west, clearing is less complete, irregular and brief.

Floes of young polar ice, arctic pack ice and sometimes ice island fragments can intrude into Viscount Melville Sound through M'Clure Strait and Byam Martin Channel. Although these floes are nearly always completely melted in Barrow Strait and Lancaster Sound, they frequently remain in Viscount Melville Sound. Very extensive clearing of ice will often be followed by a year of restricted breakup since polar floes from Byam Martin Channel can then readily enter the area.

Generally, freezeup of Parry Channel proceeds in the reverse direction. Thus, the number of ice free days in a year generally decreases from east to west (Fig. 8). In some years the formation of young ice in October is sufficient to restrict further ice movements, and Viscount Melville Sound probably supports a consolidated ice cover after mid-November.

Figure 3

Robertson Point, an example of a bedrock headland. Superimposed on the bedrock which is striking east into Byam Channel, there are traces of raised boulder beaches. A gravel beach continues from the headland towards the north but quickly disappears. The background is a vegetated sandflat. Note the stable shorelead and the nearshore ice still frozen to the bottom. GSC 202953-2 taken July 11, 1973.

Figure 4

Raised beach sequence at Kay Point (Fig. 2). Beaches are perched directly on bedrock and consist of cobbles and boulders. GSC 202593-0 taken August 3, 1973.

Figure 5

Small gravel spit on a raised beach coast. Such spits do not reflect a consistent longshore transport direction but probably are the result of a storm during favourable fetch conditions. GSC 202953-U taken on August 13, 1973.

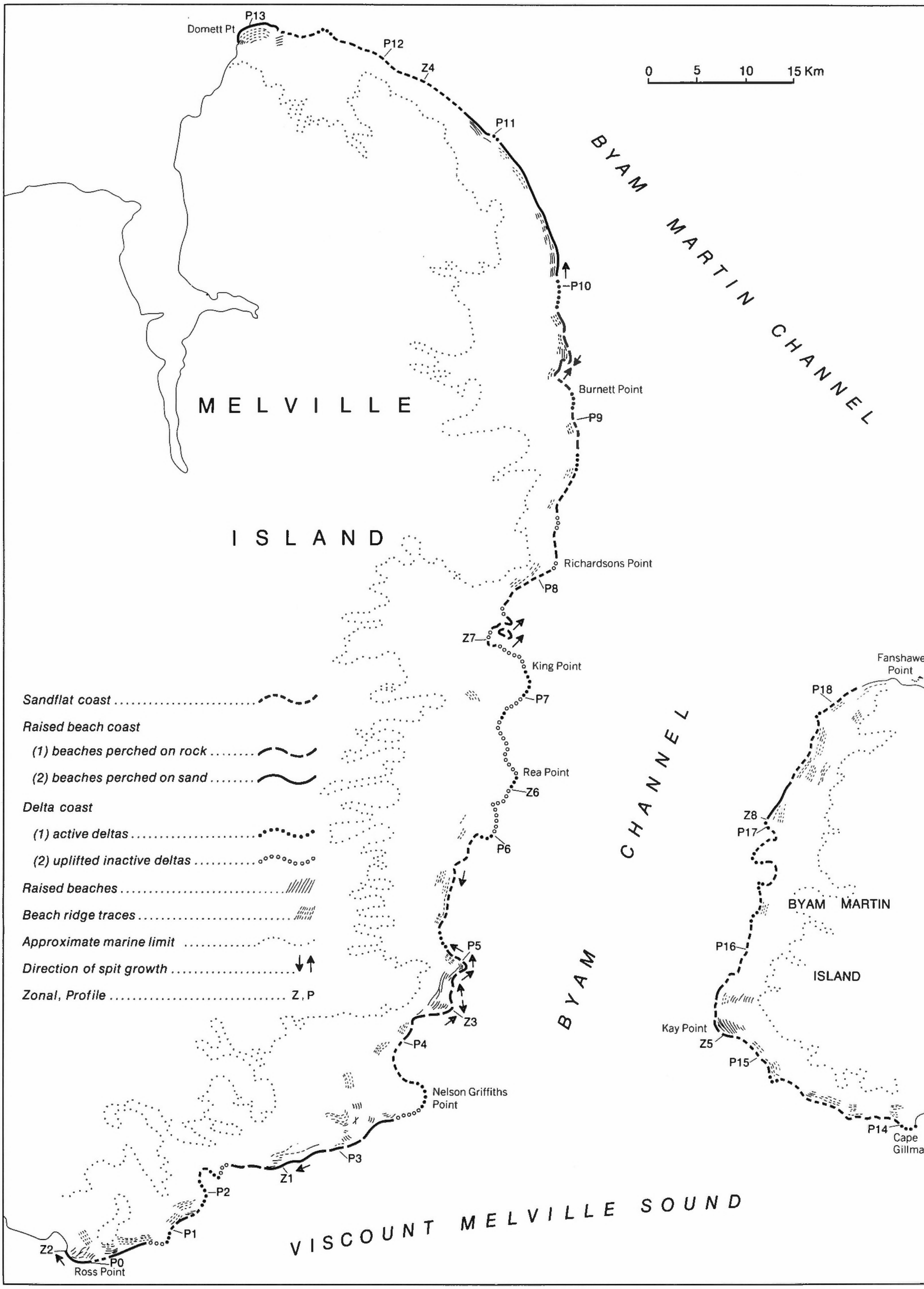
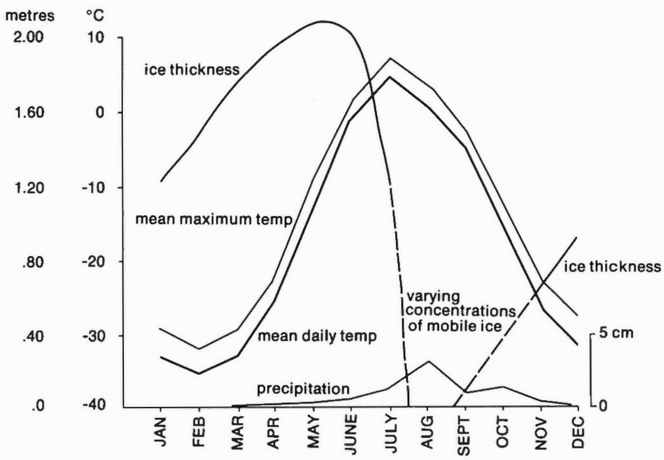


Figure 6. *Coastal types, Melville and Byam Martin islands.*



Based on 6 years of data from Rea Point

Total average precipitation = 3.57 cm

Figure 7. *Average temperature, precipitation and ice thickness at Rea Point, eastern Melville Island. (Ice thickness after Lindsay, 1969).*

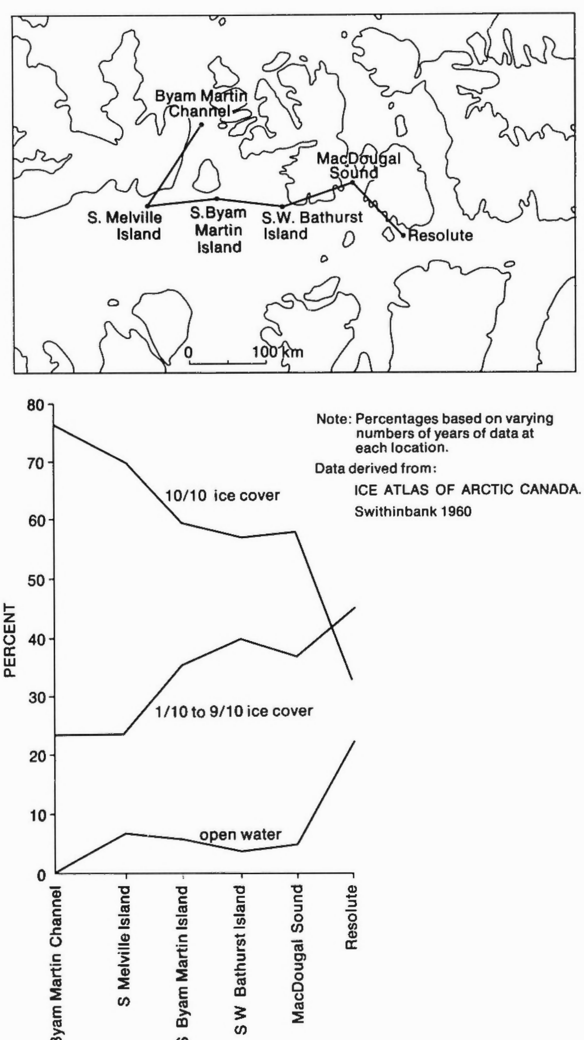


Figure 8. *Average ice cover conditions between April 16 and October 31 with respect to location.*

Observations during the field seasons showed the following sequence of events. As temperatures rose above freezing, snow melt and river flow began before ice breakup in the channel occurred. Consequently river sediments were deposited on the nearshore channel ice or carried down through strudels (Reimnitz et al., 1974) and tidal cracks into the sea water. The decreased albedo caused by sediment on ice resulted in more rapid melting of the delta fronts. Elsewhere, sheet runoff down the newly exposed land surfaces produced ephemeral deposits at the ice-beach interface which are termed by the present author as ice-foot deposits. These in turn were lowered into the nearshore waters as the ice melted.

During this period, breakup of channel ice in regions to the east of Byam Channel were causing sufficient releases in pressure for cracks to form. These cracks, produced first in Viscount Melville Sound, gradually occurred farther north up the channel. As the delta fronts became progressively more free of ice, narrow shore leads were produced between the beach and pack ice (Fig. 3). In shallow water fast ice was often seen to be frozen to the bottom and was frequently covered with ice-foot deposits. On breaking free from the bottom this ice was observed to contain quantities of sediment. Further melting of these floes resulted in redeposition of the sediment in the nearshore.

It is interesting to note that although ice affected nearshore sedimentation, it had little opportunity actually to remove sediment to the offshore. Fluvial deposition took place first on the ice, and was subsequently redeposited in situ as the delta front broke up. Ice containing sediment within shore leads was restricted by the contemporaneous presence of offshore pack ice. It was observed that sediment-laden ice melted in the nearshore well before the pack ice had allowed offshore ice rafting to take place.

Floating ice trapped in the shore lead was highly mobile, being buffeted by winds. In all probability during this time nearshore sediment was under fairly constant minor scraping and scouring by moving floes. As the shore leads widened the channel ice became increasingly mobile and susceptible to forming pressure ridges and being pushed up onto the beach (Fig. 9). It was during this time that ice movement began to be important as an active process in affecting offshore and beach morphology.

With increasing clearance, the remaining ice floes were often driven towards shore where they grounded in the shallows and formed ice fences or stoyaki (Glukhova, 1964). Pack ice, blocks of multi-year ice and ice island fragments were free to move into the channel from the north. These frequently touched and scoured the bottom before coming to a halt where, if they remained, they could become frozen in place by the onset of freezeup.

Freezeup began as sea temperatures approached -2.2°C and the spray from waves froze on the snow covered beach. Initially a slushfoot (Taylor, 1973), was formed followed by a substantial ice foot as air and water temperatures decreased. With the formation of an ice foot, beach processes came to a halt and freezeup across the channel progressed, first with the formation of nilas ice followed by increasingly thicker ice. Weather conditions and the amount of multi-year ice blocks present during freezeup dictated the composition and configuration of the nearshore ice found in the following spring.

COASTAL PHYSIOGRAPHY

Introduction

The characteristics of the coasts bordering Byam Channel have developed during Holocene emergence. Marine limit elevations show that there has been up to 100 m of emergence and the east coast of Melville Island is still recovering at a rate of approximately 0.35 cm/y (McLaren and Barnett, 1978). During emergence three principal coastal types were formed (Fig. 6).

i. Sandflat coast which constitutes 45 per cent of the present shoreline.

ii. Raised beach coast which has been further subdivided into (a) raised beaches perched on rock (11 per cent of the shoreline) and (b) raised beaches perched on sand (22 per cent of the shoreline).

iii. Delta coast which has also been divided into (a) active deltas (15 per cent of the shoreline) and (b) uplifted inactive deltas (7 per cent of the shoreline).

Each coastal type has been divided into coastal units (Table 1) comprising an uplifted, inactive (in terms of marine processes) portion, and a backshore and foreshore which comprise the beach. Within the coastal units, morphologic units such as supratidal flats, berms, interbeach lagoons, etc. have been treated as subenvironments. Definitions for the terminology used have been taken from the Glossary of Geology, American Geological Institute (1977) and rigorously applied.

Sandflat Coast

The sandflat coast (Fig. 10) is characterized by a smooth, gently sloping sandy facies, the average slope of which is 1° (± 0.7°). It extends from the present shoreline, inland to an average elevation of 20 ± 8 m and has a width of 1.2 ± 0.5 km (Table 1). The inland edge of the sandflat is usually delimited by a break in slope between the uplifted sediments and the steeper hillsides.

The flatness and uniformity of the sandy facies commonly preclude distinction of backshore and foreshore units from the older uplifted sandflat. The uplifted sandflat usually becomes progressively more vegetated inland, although the proportion of cover is too variable to use as a guide to estimate either the maximum elevation of storm surges or the relative age of the uplifted portion. Sheet wash and rill erosion during the spring melt and after rain are

Table 1. Summary of coastal morphologic and sedimentologic characteristics

GENERAL COASTAL CHARACTERISTICS				BEACH PROFILE MORPHOLOGY				
COASTAL TYPE	Mean max. elev. (m)	Mean slope (°)	Mean width (Km)	COASTAL UNIT	MORPHOLOGIC UNIT	Mean width (m)	Mean relief (m)	Mean slope (°)
Sand flat	20 ± 8	1 ± 0.7	1.2 ± 0.5	uplifted sand flat	N/A	N/A	N/A	1.8 ± 0.7
				backshore	supratidal flat	N/A	N/A	0.7 ± 0.5
					berm	23 ± 21	N/A	0.2 ± 0.3
				foreshore	beach face	N/A	N/A	2.0 ± 0.9
					ridge	3 ± 2	0.1 ± 0.0	3.4 ± 1.4
					low tide terrace	23 ± 20	N/A	1.2 ± 0.3
Raised beach	30 ± 11	2 ± 0.8	1.3 ± 0.7	uplifted raised beach complex	raised beach top	3 ± 1	N/A	flat
					raised beach face	N/A	0.8 ± 0.6	4.7 ± 2.3
					interbeach lagoon	12 ± 11	N/A	flat
				backshore	berm	6 ± 3	N/A	flat
				foreshore	beach face	N/A	N/A	8.5 ± 6.3
Delta	?	Flat	?	uplifted delta flat	N/A	N/A	N/A	flat
				backshore	supratidal delta flat	N/A	N/A	flat
				foreshore	beach face	N/A	N/A	3.1 ± 1.1

probably responsible for the variability of the vegetation cover. In areas devoid of vegetation, the uplifted sandflat frequently has a pebble and shell veneer which is the result of deflation. Often this pebble veneer allows small erosional mounds several centimetres high to develop among the rill channels.

The major characteristic of a sandflat coast is the lack of morphological evidence of former sea levels (Fig. 10). Raised beach ridges are essentially absent and only rarely can minor strandlines be seen on airphotos. There are two reasons for this. First, an uplifted berm consisting only of sand would be quickly eroded by runoff to the level of the sandflat. Second, the presence of ice in the Arctic environment prevents long periods of swell waves and the resultant formation of well-developed berms which are the result of a constructional phase of a beach cycle. It is more probable, however, for a storm to be effective during the open water season resulting in the disappearance of any constructional characteristics of the beach. The sandflat, therefore, is probably the result of a continuous succession of storm profiles undergoing uplift thus leaving no morphological traces of former sea levels.

The uplifted sandflat adjoins a backshore of extremely variable width (Fig. 11). The latter can be divided into two morphologic units; a supratidal flat which is rarely inundated and a low berm whose width averages 23 ± 21 m. The foreshore, which contains a beach face sloping at 2 ± 0.9° occasionally develops minor ridge and runnel systems (Fig. 11, profile 8). When ice conditions permitted, a gently sloping (1.2 ± 0.3°) low tide terrace was observed (Table 1).

Raised Beach Coast

As the name implies, a raised beach coast (Fig. 4, 12) is characterized by well defined ridges composed primarily of gravel that extend from the shoreline to an average elevation of 30 ± 11 m. The average width and slope are 1.3 ± 0.7 km and 2 ± 0.8° respectively. The numbers of beach ridges range from 7/km to 28/km and average 16 ± 6/km. Their average relief is 0.8 ± 0.6 m.

Unlike the sandflat and delta coasts, the coastal and morphologic units are easily distinguished from each other (Fig. 12). The uplifted raised beach complex, no longer susceptible to marine processes, has been divided into the following morphologic units (Table 1); (i) raised beach top which has an average width of 3 ± 1 m; (ii) a raised beach face which has an average slope of 4.7° ± 2.3° and (iii) an interbeach lagoon. The latter is analogous to a swale which is a shallow, trough-like depression between beach ridges and is aligned roughly parallel to the coastline. The term

SEDIMENT PARAMETERS									
GRAVEL (>-1∅)			SAND (<-1∅)						
			TEXTURE			MOMENT MEASURES			
Mean % gravel	Mean size	Mean sorting	Mean % sand	Mean % silt	Mean % clay	Mean size	Mean sorting	Mean skewness	No. of samples
1 ± 2	-2.63 ± .40	0.92 ± .04	71 ± 22	22 ± 16	7 ± 6	3.86 ± 1.03	2.06 ± .95	2.23 ± 1.75	8
1 ± 2	-2.45 ± .27	1.19 ± .57	82 ± 16	14 ± 12	5 ± 4	3.37 ± .73	1.82 ± .77	2.94 ± 1.58	11
0 ± 0	N/A	N/A	94 ± 3	4 ± 3	2 ± 1	2.67 ± .23	1.37 ± .27	4.49 ± .93	9
0 ± 0	N/A	N/A	91 ± 8	8 ± 7	2 ± 2	2.75 ± .33	1.53 ± .43	3.71 ± 1.27	5
-	-	-	-	-	-	-	-	-	8
-	-	-	-	-	-	-	-	-	5
41 ± 19	-2.71 ± .48	.89 ± .15	80 ± 10	15 ± 8	5 ± 3	2.78 ± .71	2.46 ± .61	1.90 ± 1.03	9
31 ± 18	-2.60 ± .52	.91 ± .14	77 ± 10	17 ± 7	6 ± 3	3.03 ± .72	2.60 ± .60	1.76 ± .96	9
8 ± 8	-2.41 ± .47	.83 ± .21	80 ± 11	15 ± 8	5 ± 3	3.45 ± .50	2.15 ± .44	2.45 ± .99	13
56 ± 11	-3.04 ± .46	.96 ± .08	83 ± 9	13 ± 7	4 ± 2	2.65 ± .75	2.40 ± .48	1.88 ± .75	9
49 ± 31	-3.15 ± .82	.94 ± .29	84 ± 6	12 ± 5	4 ± 2	2.60 ± .47	2.35 ± .58	2.05 ± .85	9
2 ± 4	-2.33 ± .36	.69 ± .04	84 ± 15	13 ± 14	3 ± 2	3.23 ± .58	1.62 ± .38	3.63 ± 1.26	12
3 ± 5	-2.23 ± .25	.77 ± .14	82 ± 10	12 ± 5	6 ± 5	3.36 ± .59	2.18 ± .73	2.69 ± 1.24	8
3 ± 6	not enough samples containing gravel		93 ± 8	6 ± 7	2 ± 2	2.60 ± .59	1.53 ± .32	3.89 ± 1.09	6

Figure 9

Ice push on beach at Ross Point following high south winds on July 8, 1973. GSC 203123-N taken on July 11, 1973.

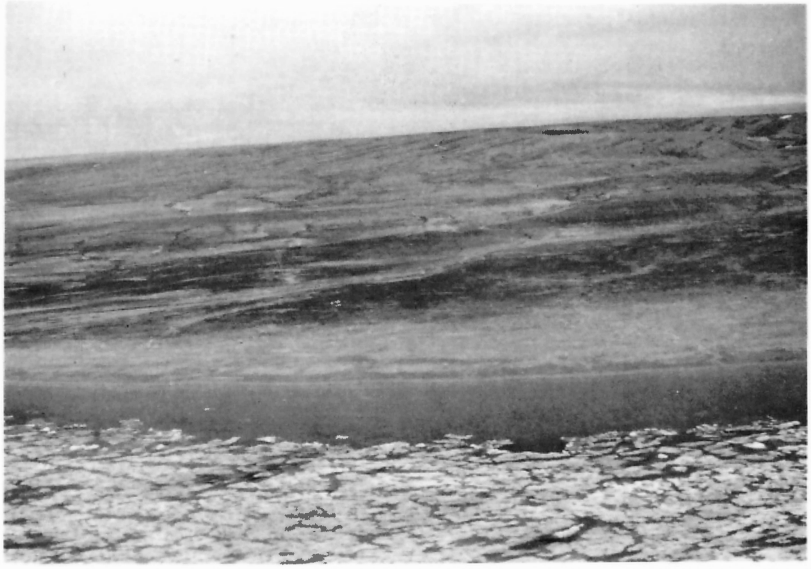


Figure 10

Typical sandflat coastline. Photo taken north of Richardson Point (Fig. 2) on July 11, 1973. GSC 202951-R

"interbeach lagoon" is used instead of swale because at the time of formation it may have characteristics which define a lagoon. With emergence, the interbeach lagoon can become intertidal and supratidal until it is removed from marine processes altogether. Once uplifted, meltwater frequently forms ponds in them. They average 12 ± 11 m in width and are usually less than 1 m deep.

The backshore of the raised beach coastal type usually contains only a berm (6 ± 3 m wide) but can include an overwash deposit and the most seaward interbeach lagoon. The high percentage of gravel (49 ± 31%) that makes up the beach allows a steep sloping foreshore (8.5° ± 6.3°) to develop which frequently contains ice push deposits (Fig. 12). Ice push deposits have been described in some detail by previous workers (Nichols, 1953, 1961; Hume and Schalk, 1964; Owens and McCann, 1970) and consist of ridges often several metres long and up to one metre high. They run parallel to the shore and can be found far above mean high water, the result of winds piling ice over the beach which in turn causes gouging, transportation and deposition of sediment.

When raised beaches are perched on rock, as on rocky headlands (Fig. 3), the foreshore can contain two more morphologic units. (i) An ice push boulder barricade which is a special form of ice push ridge and may be similar to shoreline ramparts described by Ward (1959), Nichols (1953) and Goldthwait (1957). The boulder barricade can form at or below mean low tide (Z5B, Fig. 12) and consists of a steep boulder ridge that parallels the shore for several hundred metres. (ii) A boulder and cobble pavement which is a veneer of broken bedrock underlying the boulder barricade and forms the floor of a prototype interbeach lagoon between the beach and ice push boulder barricade. The large size of the clasts in both these units made representative sampling impossible and therefore they are not included in Table 1.

Delta Coast

Each of 32 drainage basins that empty into the Byam Channel area is terminated by an active delta (Fig. 13). In many cases, the present rivers have cut through raised delta sequences (Fig. 14) showing them to consist predominantly of foreset beds dipping at 10° or more, thus classifying them as Gilbert deltas (Gilbert, 1890). Diving observations on the active delta fronts (McLaren, 1975) showed similar dips (13° to 15°) terminating at a water depth of about 10 m, indicating that the present deltas are the same type as those which have been uplifted.

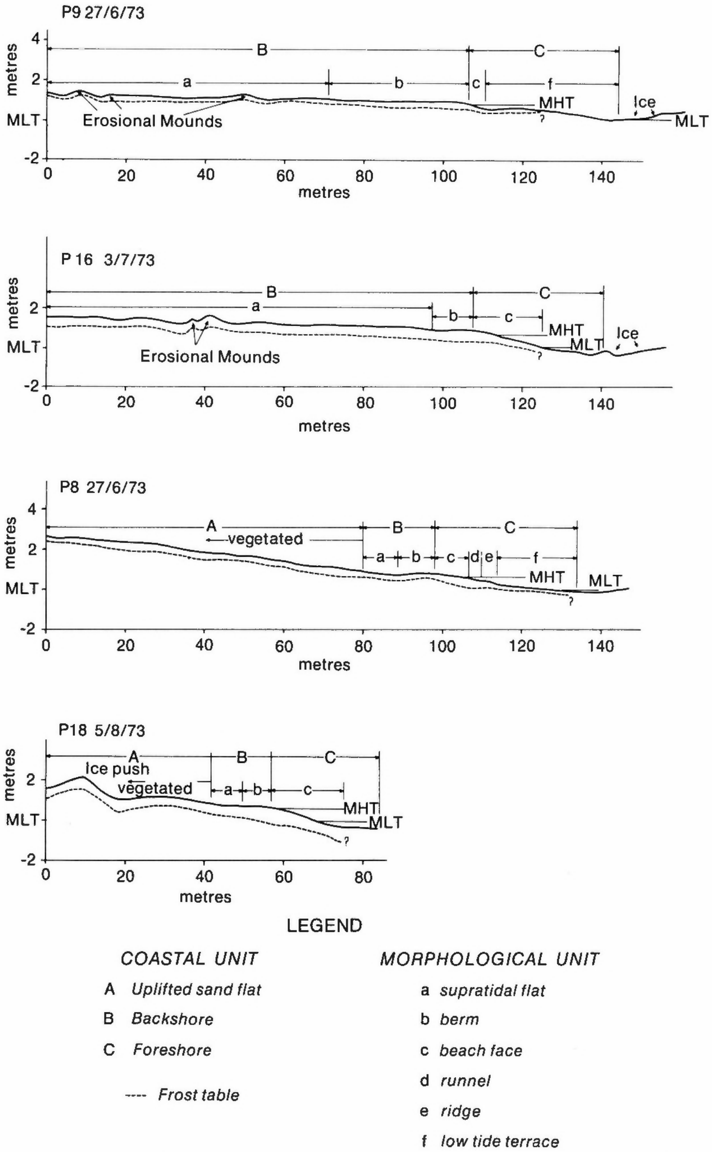


Figure 11. *Characteristic beach profiles of a sandflat coast.*

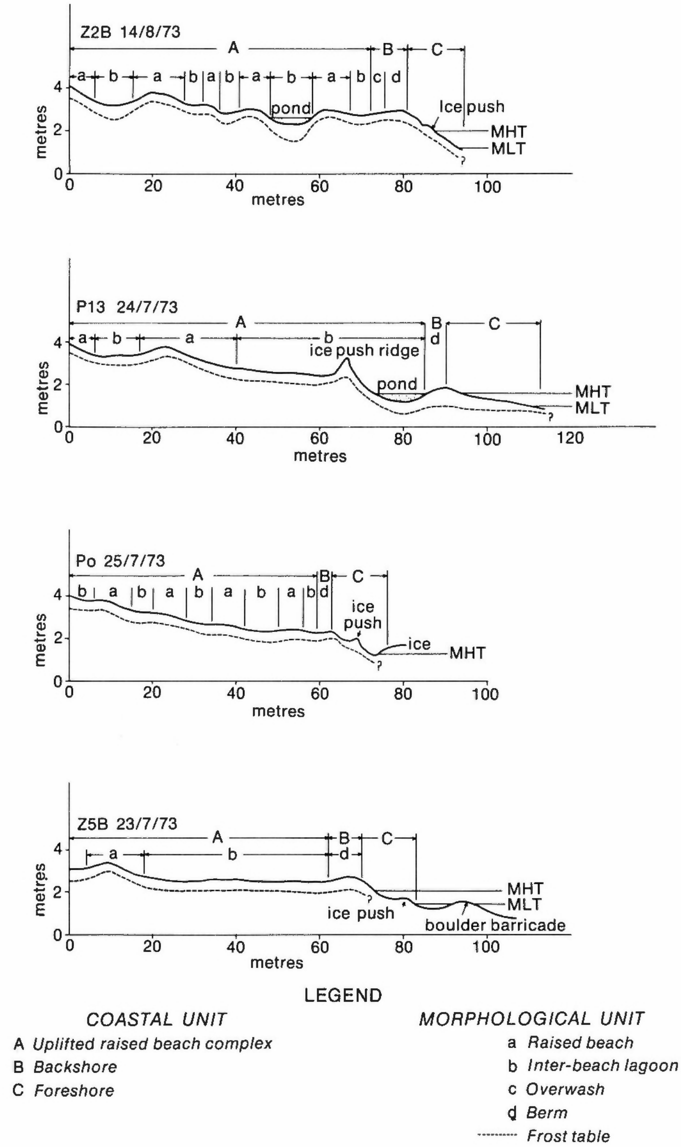


Figure 12. *Characteristic beach profiles of a raised beach coast.*

The subaerial size of the active deltas ranges from 0.06 km^2 to 5.8 km^2, the largest being at King Point (Fig. 2). Shearer (1974) has described the major components of these deltas and used the delta at Nelson Griffiths Point (Fig. 2, 13) as a type example. These components include an upper and lower alluvial plain, the active delta and an uplifted delta plain.

The upper alluvial plain begins at the point where the river is no longer confined within narrow valley walls and a braided stream pattern develops. It is characterized by longitudinal bars (Smith, 1970) which are rhomboid or diamond shaped in plan, with their long axes parallel with the flow. They are found on the surfaces of the floodplain and are active only during high discharge. Their composition is medium gravel with a sand matrix (Shearer, 1974).

The lower alluvial plain can be distinguished from the upper portion by the numerical decrease in longitudinal bars and increase in transverse bars which are tabular bodies that grow by downstream migration of foresets, more or less perpendicular to current direction (Smith, 1970). Composed primarily of sand, they have less relief and greater mobility than the bars of the upper alluvial plain. This results in a more ephemeral stream pattern in the lower reaches. The alluvial plain continues to slope gently seaward to a water depth of approximately 3 m where a sharp break in slope occurs marking the junction with the delta foresets.

The distribution and extent of the uplifted, inactive deltas are not easily delineated. In many cases they so resemble uplifted sandflats (Fig. 15, 16) that an exact outline of the deposit is difficult to determine. Generally, the immediate coast surrounding an active delta is an inactive delta front. The longest stretch of coast within this classification extends from Consett Head to King Point (Fig. 6). Vegetation is as variable as on the uplifted sandflats and the major difference from the sandflat coast is the slope of the foreshore which, for the inactive delta coast, is a former delta front and, therefore, steeply dipping at greater than 10°.

The delta coast is divided into an uplifted delta flat, a backshore which is composed of a supratidal delta flat, and a foreshore or beach face (Fig. 16, Table 1). Except for the beach face which slopes at 3.1 ± 1.1°, the backshore and foreshore are essentially flat and of widths too variable to obtain meaningful measurements.

Figure 13

Delta at Nelson Griffiths Point. GSC 202954-D taken on July 11, 1973.

Figure 14

Raised delta foreset beds exposed at Nelson Griffiths Point. GSC 202954-A taken on July 12, 1973.

Figure 15

Uplifted, inactive delta flat in vicinity of Rea Point. GSC 202953-V taken on July 11, 1973.

NEARSHORE SEDIMENTOLOGY AND PROCESSES

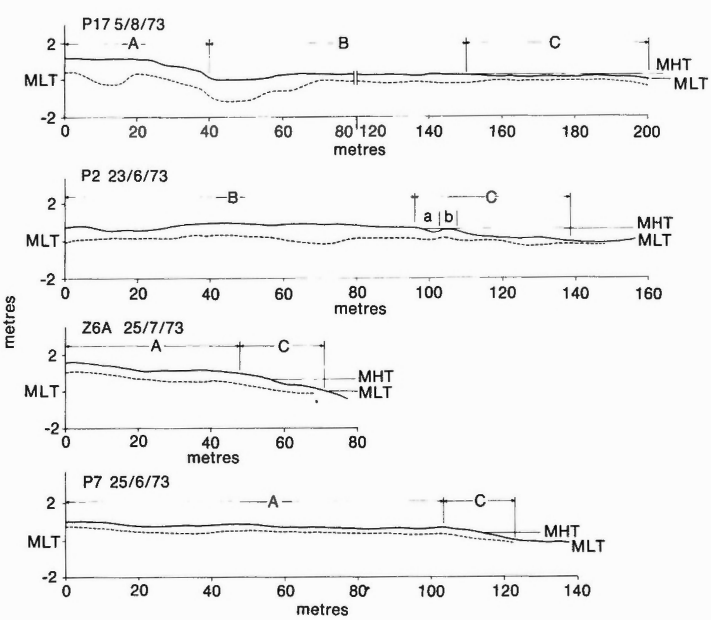
Diving Observations

Ice Scour Terminology

Diving observations to a depth of approximately 30 m in Byam Channel showed that much of the seafloor has been affected by moving ice impinging on the substrate. The resulting bottom features produced by this process have been given a variety of terms: e.g., furrow marks (Harris and Jollymore, 1974), gouges (Reimnitz and Barnes, 1974), plough marks (Belderson and Wilson, 1973), ice scores (Kovacs and Mellor, 1974) and ice scours (Pelletier and Shearer, 1972). Several other terms have been used to describe associated features. Long linear ridges that parallel each side of an ice-made track have been called scour levees (McLaren, 1975) and ridges (Reimnitz and Barnes, 1974). Scour moraine (McLaren, 1975) and push-moraine (Reimnitz et al., 1973) have been used to describe material pushed up in front of a moving ice block.

Barnes et al. (1978) pointed out that the term "ice-scour" is more in keeping with the evolution of geological nomenclature but favour "ice gouge" to avoid the process implications of the word "scour". This paper retains the term "ice-scour" since the American Geological Institute (1977) defines several types of scour with a preceding adjective (e.g., glacial scour) and there should be no confusion over the type of process involved as long as "scour" is not used by itself.

With the increasing number of observations on various types of ice-produced bottom features it is helpful to have a more rigorous terminology. The following definitions are presented as an ice-scour glossary and will be followed throughout this report.



LEGEND

COASTAL UNIT

A *Uplifted delta flat*

B *Backshore (supratidal delta flat)*

C *Foreshore*

MORPHOLOGICAL UNIT

a *runnel*

b *ridge*

----- *Frost table*

Figure 16. *Characteristic profiles of a delta coast.*

Ice-scour track

The mark left by an ice fragment that has moved through a substrate. The width of an ice-scour track encompasses the maximum width of ice-disturbed seabottom including both depressed and heaved up sediment surfaces (Fig. 17 to 20).

Single ice-scour track

In cross-section this track exhibits a single simple depression having only one slope reversal. It is formed by the incision of a single downward projecting piece of ice moving through a substrate. The scouring ice may be an ice island fragment, an iceberg, a block of multi-year ice, or a deep fragment of a pressure ridge keel (Fig. 17, 18).

Multiple ice-scour track

This track is complex in cross-section with more than one slope reversal within the depressed area. It originates by the simultaneous scraping action of several separate pendants of a pressure ridge keel on the bottom. This scour form is common in the Beaufort Sea (Lewis, 1978). Due to the irregular nature of a pressure ridge keel, the multiple ice-scour bottom contains ridges and furrows running more or less parallel to the track (Fig. 19, 20).

Ice-scour embankment

A morphological feature, commonly linear, within an ice-scour track that has positive relief relative to an undisturbed bottom. The sides of an embankment are defined as proximal or distal with increasing distance from the scour bottom.

Ice-scour lateral embankment

A linear embankment bordering one or both sides of an ice-scour track (Fig. 17 to 20).

Ice-scour terminal embankment

An embankment that terminates an ice-scour track (Fig. 17).

Ice-scour bottom

The portion of an ice-scour track that lies between the lateral embankments and generally below the level of undisturbed seabottoms (Fig. 17 to 20).

Ice-scour side

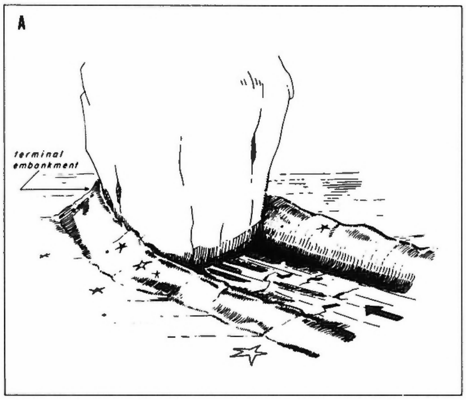
The sloping surface within an ice-scour bottom that lies below the undisturbed seabottom and that borders the proximal side of an ice-scour embankment (Fig. 17 to 20).

Ice-scour depth

The maximum depth to the scour bottom relative to the undisturbed bottom (Fig. 18, 20).

Penetration depth

The maximum depth to which ice penetrates the undisturbed bottom. In a freshly made ice-scour track, scour depth will be identical to penetration depth. In time, the scour track may be modified by erosion or deposition so that the scour depth may differ from the original penetration depth.



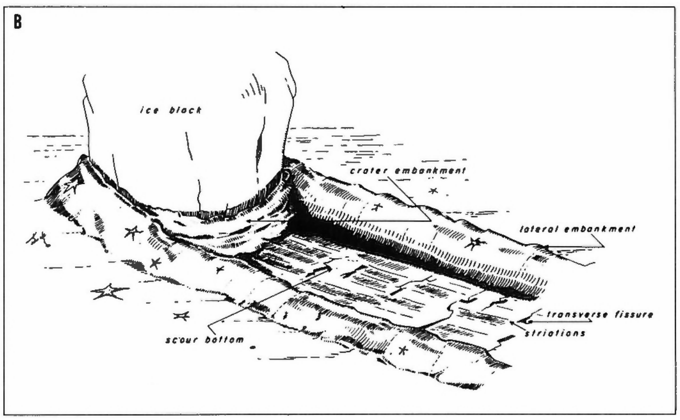


Figure 17A. *Diagrammatic sketch of an ice block moving through the substrate.*

Figure 17B. *The same block has come to a halt and downward vertical pressures form an ice scour crater.*

Ice-scour crater

The depression caused by a grounded ice block after it has become stationary. It is the result of downward vertical pressures exerted by the weight of an ice block (Fig. 17).

Crater embankment

An embankment surrounding a scour crater. Part of the crater embankment may be combined with a terminal embankment causing this segment to be higher than the rest of the crater embankment (Fig. 17).

Ice-scour ridge

A linear ridge within and parallel to an ice-scour bottom commonly within a multiple scour track. The ridge elevation is insufficient to rise above the level of undisturbed seabottom. If the ridge did extend above the level of undisturbed bottom it would by definition become an embankment, either a lateral embankment if it bounded the scour track or a "medial embankment" if it did not (Fig. 19, 20).

Ice-scour furrow

A linear depression between scour ridges within and parallel to an ice-scour bottom (Fig. 19, 20).

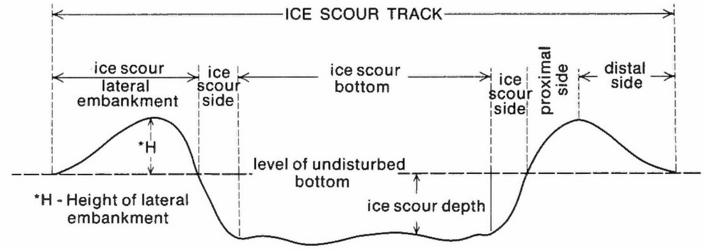


Figure 18. *Hypothetical cross-section through a single ice scour track.*

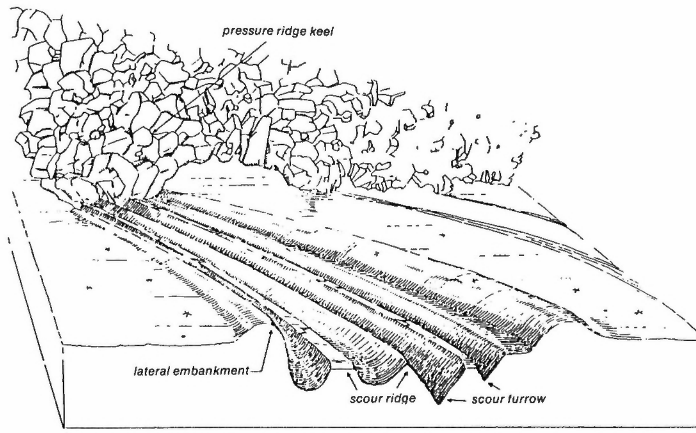


Figure 19. *Diagrammatic sketch of a pressure ridge keel scraping the substrate.*

Ice-scour groove

A linear, narrow gouge or depression parallel to and superimposed on furrows, ridges, scour sides, and scour bottoms produced by minor irregularities on the ice mass contacting the substrate. Total relative relief of grooves is less than 15 cm but greater than 2 mm.

Ice-scour striations

Small linear depressions parallel to and superimposed on furrows, ridges, scour sides, and scour bottoms produced by minor irregularities on the ice mass contacting the substrate. They are smaller and narrower than grooves with a relative relief of 1 to 2 mm.

Transverse fissures

Elongate, irregular cracks or crevasses within ice-scour bottoms orientated transversely to the scour track. They are approximately 15 to 30 cm wide and are formed by the frictional drag of the trailing edge of a moving ice block (Fig. 17).

Nearshore Environments and Effects of Grounding Ice

SCUBA diving observations indicated that there are three nearshore bottom environments with corresponding facies in Byam Channel. They are:

(a) Cobble bottom

Bottoms consisting of a pavement of pebbles, cobbles and occasional boulders were observed at 7 of the 30 dive sites (Fig. 2). With the exception of DH8 opposite Nelson Griffiths delta, all were adjacent to a raised beach coastline. Invariably the cobble pavement reflected lithologies found at the adjacent coast (Fig. 21).

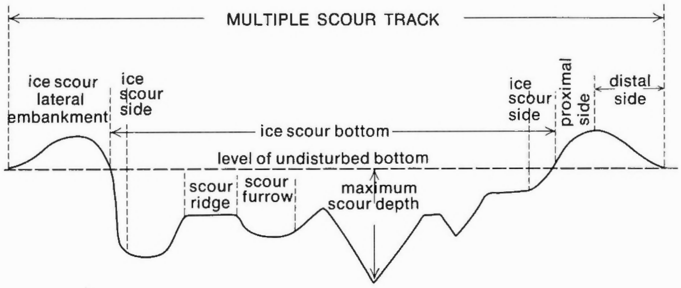


Figure 20. *Hypothetical cross-section through a multiple ice scour track.*

Observations at DH11, 20 and 22 indicated that rocky headlands such as Robertson Point (Fig. 2) probably continue offshore as bedrock bottoms with an overlying cobble pavement. A fine grained sediment cover was usually absent but the friable nature of the Hecla and Griper Bay sandstone sometimes resulted in a sandy matrix among the pebbles and cobbles.

All rocky bottoms contained some evidence for ice scouring. Commonly scour tracks were apparent by the absence of kelp **(Laminaria)** normally attached to the undisturbed bottom (Fig. 22). Scour bottoms tended to be shallow (30 to 60 cm deep), flat and wide (1 to 13 m). Debris comprising broken pelecypod and sea urchin shells frequently accumulated in the scour bottom. Low (generally <50 cm in height above undisturbed bottom) lateral and terminal embankments consisted of gravel, cobbles and boulders of the pre-existing pavement as well as occasional boulders of freshly torn-up bedrock.

Where fine sediment was present in sufficient quantity a veneer of compressed sand and silt was commonly "smeared" along the sides and bottom of the scour track. This veneer commonly contained grooves and striations (Fig. 23). Torque readings from a vane shear meter imbedded in the surface sediment, expressed as sediment shear strength (kg/cm^2) illustrate the difference between compressed fines on the scour bottom and the loose, newly ploughed-up sediments on the lateral embankments (Table 2). The shear strength is 3.5 times greater in the scour bottom than in the lateral embankments. These values are only approximate and should probably be much higher for the scour bottom since in many cases the divers were unable to press the shear vanes into the sediment at all.

(b) Shallow sandy bottom

A sandy facies was observed as a submarine continuation of the sandflat coastal type where it sloped at about 2° to a depth of 7 m. A similar facies was found on one occasion adjacent to a raised beach coastal type. Both active and inactive delta fronts showed a more steeply dipping (>10°) sandy facies which extended to somewhat deeper depths of 9 or 10 m.

In general sandy bottoms showed little evidence for ice scour in spite of many dives taking place close to grounded ice blocks and ice fences. Currents were nearly always felt by the divers in the shallow water under the ice and ripple marks were commonly observed moving parallel to shore. Scour tracks formed in such mobile sand were evidently infilled and obliterated rapidly.

(c) Sand-silt-clay bottom

A sand-silt-clay facies was observed in 12 of the 30 dive sites. It was found offshore from the 7 to 10 m isobath and evidence from a single seismic line indicates that it is overlain by silt and clay beyond water depths of 100 m (Polar Gas, personal communication). Seismic and electrical resistivity measurement at DH1, 7 and 9 (Fig. 2) show the sand-silt-clay facies to be 4 to 6 m thick (McLaren et al., 1975). At most dive locations, pebbles and cobbles of local bedrock were observed both resting on the bottom and in cores.

Such bottoms were highly variable with respect to the degree of ice scouring. Completely undisturbed bottoms were present at three dive locations (Fig. 24). Other locations containing old scour tracks appeared as gently undulating bottoms (Fig. 25), consisting of subdued parallel valleys up to several metres wide with less than one metre of relief.

Two types of freshly scoured bottoms were observed; those in which the surface appeared to be so churned by ice activity that undisturbed areas did not exist (Fig. 26), and those where a scour, its embankments and an undisturbed bottom could all be clearly defined (Fig. 27). In the latter, scour was observed to reach depths of 1.5 m and to produce lateral embankments up to 2 m high. More commonly, however, they exhibited less than 1 m of total relief.

Within scour bottoms, the sediment was compressed to such a degree that frequently it was impossible to take cores. By contrast the embankments were more loosely compacted than either the track or the undisturbed sediment beyond the scour. Values from a vane shear meter illustrate the differences in sediment shear strength obtained in the various scour morphologies (Table 3). The scour bottom has a shear strength of approximately 0.09 kg/cm^2 which is twice as great as an undisturbed bottom (0.04 kg/cm^2) and nearly five times greater than a recently produced lateral embankment (0.02 kg/cm^2).

Table 2. Vane shear readings (kg/cm^2)[1] from a cobble bottom (DH11)[2]

	Scour bottom	Lateral embankment
	.10	.02
	.09	.03
	.14	.04
	.14	.03
	.20	.03
		.06
Mean	.14 ± .04	.04 ± .01

[1] kg/cm^2 appears to be the most common metric measurement of shear strength (see Marine Geotechnology, 1976, Vol. 1). More correctly this measurement should be expressed as kilograms force/cm^2 (1 kg/cm^2 = 98.1, kPa = 14.2 psi).

[2] Penetration depth of shear vane into sediment = length of shear vane = 1.9 cm.

Table 3. Vane shear readings (kg/cm^2) from a sand-silt clay bottom (DH1)[1]

	Undisturbed bottom	Scour bottom	Lateral embankment
	.04	.09	.02
	.04	.08	.02
	.04	.07	.01
	.04	.09	.01
	.03	.10	.02
	.04		.02
	.04		
Mean	.04 ± .00	.09 ± .01	.02 ± .01

[1] Penetration depth of shear vane into sediment = length of vane = 1.9 cm.

Figure 21

Example of a cobble bottom made up of Hecla Bay sandstone. DH8 (Fig. 2), water depth 11 m. GSC 202955-0

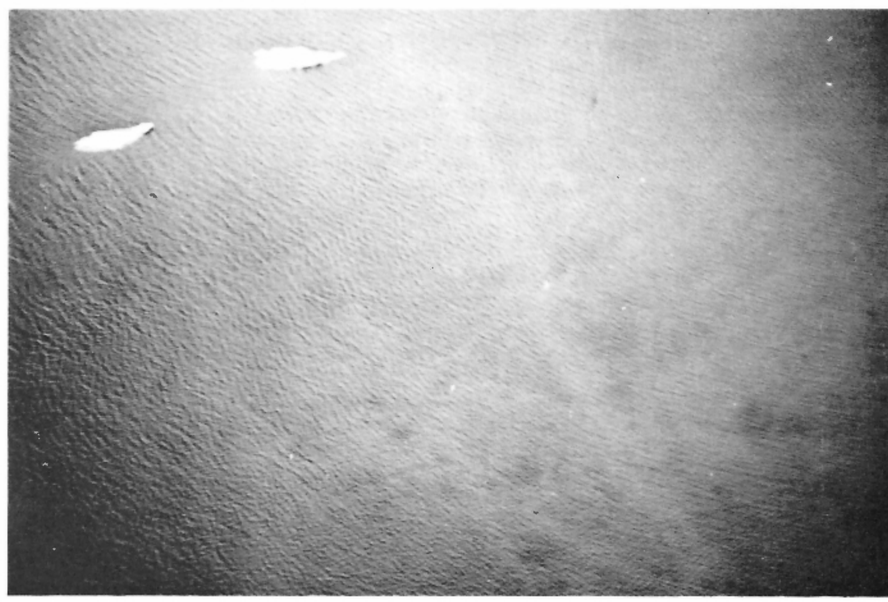


Figure 22

Scour tracks visible through the water near Burnett Point (Fig. 2). Black areas are kelp attached to rock which is absent inside the tracks. GSC 202954-Y

Figure 23

Striated side of a lateral embankment in a cobble bottom. Relief is approximately 80 cm. GSC 202955-M

Figure 24

A vegetated, undisturbed sea bottom in the sand-silt-clay facies. DH25, water depth 24 m. GSC 202842-T

Figure 25

An "old" scour track in the sand-silt-clay facies. Note the vegetated bottom and subdued relief. A sea anenome is in the foreground. DH13, water depth 13 cm. GSC 202842-S

Figure 26

Totally disturbed bottom in the sand-silt-clay facies consisting of a confused agglomeration of ice scour embankments. DH12, water depth 26 m. GSC 202842-R

Figure 27

A grounded ice block and its associated lateral and terminal embankments. The lateral embankment is approximately 80 cm high. DH2, water depth 15 m. GSC 202842-Q

Figure 28

Parallel grooves in a scour bottom formed in the sand-silt-clay facies. Note the absence of burrows. DH2, water depth 15 m. GSC 202842-P

Figure 29

Transverse fissures in a scour bottom. Scale is 30 cm long. DH1, water depth 11 m. GSC 202955-F

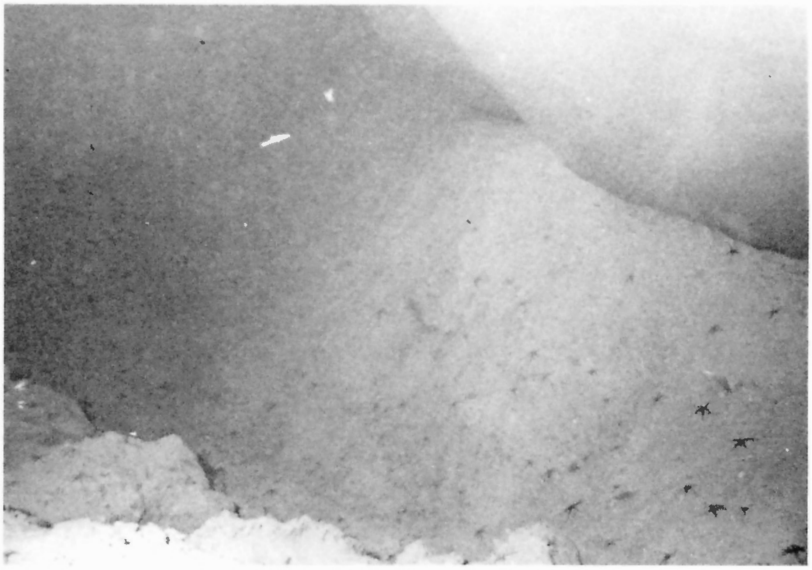
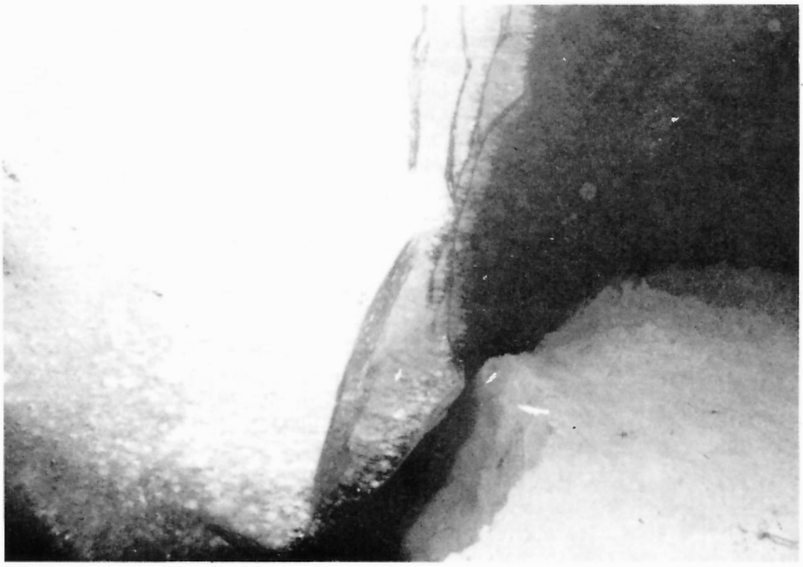


Figure 30

Crater embankment completely surrounding the base of a grounded ice block. DH2, water depth 15 m. GSC 202955-D

Figure 31

Grounded ice block and compressed inside wall of the crater embankment. DH7, water depth 13 m. GSC 202955-C



The scour track was frequently striated and grooved (Fig. 28). In some instances transverse fissures 15 to 30 cm wide were formed in the newly compressed sediment by the frictional drag of the lee side of the moving ice block (Fig. 17, 29).

Where stationary ice blocks and their associated scours were seen together, the block had commonly settled into the sediment to form a scour crater deeper than the linear scour bottom formed while the block was in motion. A crater embankment completely surrounded the ice block (Fig. 17, 30) even on the upstream side of its previous motion. Thus the linear scour bottom terminated by disappearing under the crater embankment. Where the ice had melted back from the embankment sides, the walls were seen to be highly compressed and consolidated (Fig. 31). One such crater was 3 m deep and was actively infilling with unstable material slumping down the steep walls.

A totally disturbed sand-silt-clay bottom appeared as a confused conglomeration of chaotically churned, compressed and torn-apart sediment. The embankments contained compressed, equidimensional (20 to 40 cm) blocks of sediment derived from former scour tracks. Many of the heaved-up blocks still had grooves and striations visible indicating they were previously part of a scour bottom.

Flora

The abundance of vegetation appeared to be dependent on at least three factors, namely the nature of the substrate, the amount of available light and the degree to which the bottom has been affected by grounding ice. The first, the nature of the substrate, determined the ease which algae could attach themselves to the bottom. Plants were either rare or absent on shallow sandy bottoms since sand is a poor substrate for marine algae to live (R.K.S. Lee, personal communication). Furthermore, the frequent grounding of ice in the shoreleads and the observed increase in currents in the shallow water under the ice would inhibit growth. The occasional observations of ripple marks showing sediment movement parallel to the shoreline indicate that the sandy facies is relatively mobile and would not allow an algal cover to stabilize.

In marked contrast to the sandy bottom was the cobble bottom which invariably contained vegetation attached to the large and abundant clasts. The sand-silt-clay bottom, although containing the same variety of algae as the cobble bottom, supported a more variable degree of cover ranging from virtually barren to prolific growths. Of particular importance was **Laminaria saccarina** and **L. solidungula** (kelp) which were commonly attached to rocks and pebbles but were occasionally rooted in the sand-silt-clay facies.

Chaetomorpha melagonium and **Polysiphonia arctica** frequently formed a low-lying carpet giving the substrate a meadow-like appearance (Fig. 24, 25). The presence of such a carpet attached directly to the sand-silt-clay bottom is an indication of an extremely stable substrate in a nondepositional environment (R.K.S. Lee, personal communication).

The second factor, the amount of light that reaches the substrate, is a function of depth and turbidity of the water and the nature of the ice cover. Turbid water was only rarely encountered throughout the full depth of the water column and in such cases vegetation was very scarce. Usually, a layer of freshwater derived either from rivers or from the ice melt itself, floated between the ice and the more saline water below. This layer was commonly only 1 or 2 m deep and the degree of its turbidity greatly affected the amount of light penetrating to the bottom. Where this layer was absent, more prolific vegetation could be expected.

The nature of the ice cover also appeared to be important. First year ice was grey and saturated with brine allowing little light penetration. Second year ice and older ice was deep blue and easily transmitted light thereby providing good visibility and apparently good growth conditions for vegetation. A glow of light normally surrounded the base of any grounded ice block frozen into first year ice, and on at least one occasion nearby benthic vegetation was observed to be prolific. Farther away from the ice block the substrate became barren as light intensity fell off. Two dives took place through cracks in first year ice. Along the length of the crack, vegetation flourished and on either side in darker water it was apparently absent. In this case, the cracks had not been open more than a week. Insufficient information is available to conclude that vegetation can take over a barren substrate within a few days, but the observations do show that ice cover must make distribution of plant life complex. Open water conditions vary from year to year and the type of ice cover and the distribution of cracks during breakup are also probably never duplicated from season to season. In addition, the position of grounding ice blocks occurs haphazardly thereby randomly changing local light conditions.

The third factor affecting vegetation cover is the degree to which the bottom has been ice scoured. Ice moving through the substrate obliterates the vegetation (Fig. 22). In cases where the bottom was churned by ice activity to such an extent that no undisturbed bottom existed, vegetation was virtually absent.

The extent of algal growth in a scour track gives an impression of age, although from the above discussion it is probably unreliable if takeover is rapid. On two dives the scour appeared "fresh" but plant growth was equally abundant within and outside the tracks. The visibility in both dives was exceptionally clear and may account for a rapid recovery in the disturbed areas. It is unlikely, therefore, that a method of estimating the age of a scour could be determined by the rate at which vegetation re-establishes itself.

Fauna

Invertebrate collections were identified by the Canadian Oceanographic Identification Centre (see Report Number 160, Benthos, C.O.I.C. reference number 41B). The majority of the 117 species identified were of Atlantic origin and many have circumpolar distribution. Fewer than a dozen endemics were present. Three new records for the area comprise the pycnogonid, **Boreonymphon compactum**, the amphipod, **Hippomedon gorbunova**, and the bryozoan, **Escharella immersa** (C.O.I.C. Report Number 160).

Figure 32. *Core from a recently made lateral embankment (DH29). No surface oxidation is present. GSC 202955-Q*

Similar to the observations made on the vegetation, shallow sandy bottoms contained both the least variety and least numbers of species. A greater abundance was observed on cobble bottoms, whereas the sand-silt-clay facies contained by far the greatest number of different species ranging from 5 to 73. The latter occurrence was an undisturbed bottom at a depth of 25 m in exceptionally clear water which may have been partly responsible for the large number. Present on all bottoms and usually abundant were Asteroids (star fish), Pelecypods, Echinoids (sea urchins), Gammarids, Gastropods, Harpactipoids, Isopods, Ophiuroids (brittle star), and Polychaetes (worms).

Of interest to this study are those animals that affect the sediment. The sand-silt-clay bottom contained a large variety of burrowing organisms, few of which have been satisfactorily identified. Known burrowers that were collected comprise several Pelecypods, particularly **Mya truncata** whose siphon could reach depths of 25 cm, and various Polychete worms including **Capitella capitata, Lumbrineris fragilis, Pista flexuosa** and **P. maculata.** In an undisturbed bottom as many as 200 burrows of all sizes, ranging from 1 to 5 cm across, could be counted in one square metre indicating that bioturbation is likely an important occurrence. The displaced sediment mounds surrounding burrows were also variable in size. Many holes had no mound at all whereas others were commonly 2 or 3 cm high. One organism (never identified) produced clusters of steep-sided mounds that reached over 7 cm high.

No burrows were seen in a freshly made scour bottom. However, lateral embankments composed of loose sediment were initially inhabited preferentially by burrowing organisms. In older scour, burrowers were seen penetrating compressed blocks of sediment contributing to the mechanical disintegration of scour tracks.

Crawling organisms imprinted numerous tracks on the sediment surface. Ophiuroids were omnipresent and their mobility allowed them to be the first to re-populate a scour bottom (Fig. 28, 29). Distinctive tracks were also made by Asteroids (star fish), Gastropods, Isopods and some of the Pelecypods. Sessile animals rooted into the sediment were also abundant. Three included Actinaria (sea anenomes), Ascidacea, Bryozoans, Crinoids, Holothurians and Hydroids.

Sedimentology

Core Description

Forty-one cores were collected from Byam Channel from all types of bottom and in particular, from various locations with respect to ice scour morphology. Of these, only one was obtained from a cobble bottom, eight were taken from a shallow sandy bottom and the remainder were from the sand-silt-clay facies. The cores yielded some or all of the following characteristics:

(i) Surface oxidation: Twenty-two per cent of the cores from the sand-silt-clay bottom contained a rust coloured oxidized surface layer, 0.5 to 5 cm thick. The sediment of the oxidized layer was identical to the underlying facies. The presence of such a layer appeared random, occurring in undisturbed bottoms as well as freshly made scour bottoms. Although an ice scour must initially destroy the nature of the sediment surface, it appears that oxidation of the newly exposed sediment, if it occurs, can happen relatively quickly. For example, surface oxidation was observed on one core which was taken from immediately behind a grounded ice block, the scour track of which was probably made in the fall of the previous year. The track, therefore, was much less than one year old. In other cases, undisturbed bottoms, embankments and scour bottoms showed no evidence of surface oxidation. No cores from the shallow sandy bottom or the single core from the rocky bottom had a similar oxidized layer.

(ii) Vertical facies changes: In all but one of the cores from the sand-silt-clay bottom a single facies was observed throughout the length of the sample. The exception, was a core from a lateral embankment which had 4 cm of well sorted sand overlying the sand-silt-clay facies. The sand has been interpreted as a lag deposit.

Only one core from the submarine extension of a sandflat had a gradation to a more coarse grain size with depth. This sample was exceptional whereas the others maintained a single facies. Samples from the delta fronts typically contained laminae of silt and clay interbedded with thicker units of sand.

(iii) Black bands: Common to nearly all the cores from the sand-silt-clay facies was the presence of black bands (Fig. 32). These were never distributed evenly throughout the cores and could range from an indistinct black mottling to well defined, sharp zones. They varied from being in groups less than 0.5 cm apart to 10 to 15 cm spacings. Of 10 cores from freshly scoured features such as embankments and scour bottoms, only two were devoid of black bands. Thus, scouring either fails to disturb greatly the sediment, or the black bands reform in a newly disturbed bottom.

Separate grain size analyses showed that there were no grain size differences or gradations between the black bands. Radiographs of unsplit cores showed no equivalent laminations further emphasizing the fact that the black bands have no relationship to structural patterns or to grain size differences.

The sediment between black bands was characteristically coloured olive grey to dark grey and could contain varying amounts of black mottling. The latter was commonly observed in cores from the shallow sandy facies which in some cases contained as much as 90 per cent black areas. Bands were either indistinct or absent from cores from the shallow sandy bottom.

The chemical constituents analyzed from 12 samples of black bands, 24 from sediment with varying degrees of black mottling and 20 from sediment devoid of black bands, show little variation (Table 4). Some trends are seen in the mean values; for example potassium increases slightly whereas calcium decreases when a light band is compared with a black. However only one element, sulphur, is significantly different at the 0.05 level. It is seen to increase from 0.05% in the light band to 0.12% in the black.

Of particular interest is the lack of difference in the organic carbon content (Table 4). If each black band represented a reduced organic layer, a sharp increase in organic carbon would be expected. Since there is no significant increase in the organic carbon content, it can be concluded that the bands are not buried organic layers. The alternative is, therefore, that they are forming diagenetically. They are also able to reform rapidly in newly disturbed sediment such as a lateral embankment (Fig. 32).

It is suggested that the black bands are a result of a diffusion process or liesegang banding. The phenomenon of rhythmic chemical reactions with periodic formation of insoluble precipitates has been known since the early part of this century (Liesegang, 1913). Berner (1969) synthesized iron sulphur liesegang banding in a sediment whose organic and iron contents were carefully measured.

The sediments of Byam Channel have the following characteristics in common with the conditions specified by Berner (1969) which may allow the bands to occur: (i) Organic fragments are observed in the cores, probably due to the mixing and burial of an organic substrate by ice action; (ii) An iron content which varies little throughout the vertical sediment column. Bacterial action on the organics produces H_2S which is known to be mobile in the sediment. Reaction of the H_2S with reactive iron will result in a complex precursor iron sulphide mineral which will form a black precipitate (Berner, 1969). The precipitate is unstable for the black bands oxidize and disappear from view in an opened core within a few hours.

(iv) Pebbles: Nineteen of the thirty-two cores from the sand-silt-clay bottom contained gravel sized sediment distributed randomly throughout the sample. No pebbles were present from the shallow sandy bottom. Initially ice rafting was considered to be the mechanism for this deposition. This theory was rejected because (a) the pattern of breakup inhibits nearshore ice that may contain sediments from moving into the offshore, (b) all the pebbles consisted of local bedrock lithologies which would not be the case if sediment laden ice drifted in from farther afield and (c) numerous diving observations failed to see any pebbles incorporated into the underside of pack ice or multi-year ice blocks. Similar conclusions were formed by Reimnitz and Barnes (1974) for ice rafting as a process in the American Beaufort Sea.

(v) Shells: Whole or broken shell fragments were found in all cores from the sand-silt-clay facies but were absent in the shallow sandy facies. Five shells were radiocarbon dated (Table 5), the oldest (GSC-2095; 1760 ± 200 years) found 15 cm below an undisturbed surface. This depth is well within burrowing range of the species **Mya truncata** and suggests that little, if any, burial by sedimentation has taken place.

Two cores from the scour bottom of an old, subdued ice scour track yielded shells of **Astarte borealis** (GSC-2336 and GSC-2303) at 13 and 18 cm respectively. Again, the burial depths probably do not represent sedimentation since the deeper shell is 400 years younger than the shallower shell (Table 5). Another sample of **Astarte borealis** (GSC-2288), taken from a subdued lateral embankment of the same scour track was more deeply buried than the other two shells. Found at 26 cm, it yielded a date of 820 ± 100 years (Table 5). Since **Astarte borealis** is not a burrower and lives in the first few millimetres of sediment (Stanley, 1970) it is suggested that the three shells have been buried by the scouring process. The ice scour, therefore, must have occurred sometime after 620 ± 90 years ago, the age of the youngest shell.

A fifth shell (GSC-2258, Table 5) was collected from the top of a core taken in a freshly made lateral embankment within 5 m of the grounded ice block. In appearance, the embankment was a chaotic assemblage of compressed blocks of sediment. The core tube was deliberately placed onto one of the compressed blocks. The date of the shell (590 ± 110 years) is probably not indicative of little disturbance by scouring; rather it is believed to be coincidental that an old shell was found at the top of an embankment instead of being buried.

The radiocarbon dates show no relationship between age and depth of burial suggesting that their depth is the result of sediment disturbance by ice scouring and not by sedimentation. Shells of ages greater than those shown in Table 5 may be rare since it is apparent that ice scouring tends to break them into fragments too small for satisfactory dating.

Grain Size Analyses

Samples for grain size determinations were derived from cores (average length 33 cm) collected by SCUBA from most of the dive hole localities (Fig. 2). Both the number of cores from each dive site as well as the specific locations of the cores with respect to ice scour morphology were variable. Grain size data were averaged at each locality in order to develop a representative textural description of the bottom. Because core samples were too small to yield meaningful statistics for sizes larger than 2 mm (gravel), only the sand and smaller-sized fractions were analyzed (Table 6).

Table 4. Chemical constituents (%) of 56 samples from 8 cores, Byam Channel (Analyzed by J.L. Bouvier, Analytical Chemistry, Geological Survey of Canada)

T = Trace (.01%)		C (organic)	MnO	TiO_2	CaO	K_2O	SiO_2	Al_2O_3	MgO	FeO	Fe_2O_3	Na_2O	P_2O_5	CO_2	H_2O	S	Zr	Sr	Rb	Zr	Ni	Ba
Light (no black bands) 20 samples	Mean	.30	.03	.69	.35	1.38	80.8	8.24	1.09	1.37	1.38	.74	.13	.37	2.68	.05	.03	T	T	T	T	.03
	%	.08	.01	.20	.14	.46	7.15	3.14	.39	.71	.61	.20	.04	.12	1.13	.01	.00	--	--	--	--	.01
Mottled 24 samples	Mean	.33	.03	.70	.33	1.42	80.6	8.39	1.10	1.30	1.48	.76	.15	.35	2.73	.07	.03	T	T	T	T	.03
	%	.08	.01	.16	.07	.41	6.02	2.70	.32	.54	.61	.21	.16	.11	.98	.02	.00	--	--	--	--	.01
Black bands 12 samples	Mean	.34	.03	.69	.30	1.47	79.9	8.59	1.11	1.38	1.55	.78	.12	.28	2.92	.12	.03	T	T	T	T	.03
	%	.08	.01	.23	.07	.58	7.89	3.74	.42	.86	.68	.23	.05	.10	1.34	.03	.00	--	--	--	--	.01

Table 5. Radiocarbon dates of marine shells in Byam Channel Sediments

Location (Fig. 2)	GSC ^{14}C Date No.	Water Depth	Depth in Core	Materials Dated	State of Bottom	Age B.P.
DH9	GSC-2095	20 m	15 m	**Mya truncata**	undisturbed	1760 ± 200
DH28	GSC-2288	11	26	**Astarte borealis**	"old" scour embankment	820 ± 100
DH28	GSC-2336	11	13	**Astarte borealis**	"old" scour bottom essentially undisturbed	1020 ± 80
DH28	GSC-2303	11	18	**Astarte borealis**	"old" scour bottom essentially undisturbed	620 ± 90
DH29	GSC-2358	11	0-4	**Astarte borealis**	very fresh scour embankment	590 ± 110

Table 6. Average grain size characteristics for nearshore samples, Byam Channel

		Texture			Moment Measures (> - 1∅)			
Type of Bottom	Dive Hole	% Sand	% Silt	% Clay	Mean Size	Sorting	Skewness	Depth
Cobble Bottom	DH11	71	21	8	3.93	2.51	1.75	9
	DH15	94	3	3	3.08	1.60	4.03	6
Shallow Sandy Bottom	DH4	37	46	17	5.50	2.89	0.83	3
	DH14	91	5	4	2.74	1.69	3.64	5
	DH16	96	2	2	2.65	1.42	4.87	7
	DH18	71	22	7	3.94	2.35	1.91	7
	$DH_{23}S_2$	96	2	2	2.79	1.28	5.06	3
	$DH_{23}S_3$	66	27	7	4.33	2.20	1.99	5
	$DH_{23}S_4$	45	43	12	5.12	2.62	1.37	9
	DH24	86	9	5	3.41	1.89	3.19	5
	DH26	81	14	5	3.71	1.85	3.09	14
	Mean	79 ± 18	15 ± 14	6 ± 4	3.59 ± 0.87	1.91 ± 0.46	3.14 ± 1.36	6 ± 3
Sand-Silt-Clay Bottom	DH1	22	52	26	6.58	3.07	0.51	11
	DH2	48	35	17	5.17	3.23	0.81	15
	DH3	30	49	21	5.99	3.21	0.38	14
	DH5	30	49	21	5.92	3.21	0.39	14
	DH6	14	51	35	7.33	3.03	0.16	24
	DH7	58	31	11	4.56	2.57	1.64	13
	DH9	32	40	28	6.52	3.47	0.26	20
	DH10	19	49	32	7.05	3.20	0.45	25
	DH12	51	29	20	4.61	2.70	0.77	26
	DH13	44	43	13	5.01	2.72	1.26	13
	DH19	34	37	29	6.32	3.48	0.26	18
	DH27	12	61	27	7.01	2.78	0.45	15
	DH28	37	48	15	5.21	2.69	1.29	12
	DH29	34	49	17	5.61	2.85	0.98	12
	Mean	33 ± 14	45 ± 9	22 ± 7	5.92 ± 0.92	3.02 ± 0.30	0.69 ± 0.45	17 ± 5

The nature of the cobble bottom made representative sampling impossible. Two samples from the sandy matrix between cobbles showed 36% and 18% gravel content with the remaining material consisting mainly of very fine sand (Table 6).

The shallow sandy bottom is characterized by poorly sorted (1.91 ± 0.46) very fine sand (mean grain size 3.59 ± 0.87) consisting of approximately 79% sand, 15% silt and 6% clay (Table 6; Fig. 33). All the samples showed a strong positive skewness (3.41 ± 1.36) indicating a tendency for the grain size distribution to have a tail towards the fine material.

The mean grain size of the sand-silt-clay bottom (5.92 ± 0.92) indicates the sediment is predominantly medium silt with an average composition of 33% sand, 45% silt and 22% clay (Table 6; Fig. 33). It is poorly sorted (3.02 ± 0.30) and has a considerably less positive skew than the shallow sandy bottom (0.69 ± 0.45). Gravel composition of the cores ranged from 0% to 22%.

The correlations among the composition variables are all very good. They indicate that as the per cent sand increases, silt and clay both decrease (Table 7). Sand also decreases with depth (r = -0.71) and silt and clay have a corresponding increase (r = 0.60, r = 0.83 respectively). These relationships suggest two fundamentally different sedimentary models. **Model I:** Land derived sediment is becoming progressively finer as water depth increases (Revelle et al., 1939). **Model II:** There is no land derived sedimentation occurring; rather the original sediment in the deep water contains sand, silt and clay, of which the silt and clay are increasingly removed as depth decreases and possibly deposited in the deeper water. This would result in higher proportions of sand in the shallows.

The other correlations can all be explained with either of these two models. Sorting becomes increasingly poor as mean grain size decreases (Fig. 34A) and both these variables are positively correlated with depth (Table 7). In materials finer than fine sand, it has been shown that sorting frequently deteriorates as mean grain size decreases (King, 1972). Since silt and clay increase with depth, it follows that sediment will also become less well sorted. The relationship between skewness and mean grain size (Fig. 34B) indicates that as the sediment becomes finer, positive skewness decreases. Skewness also decreases with depth. These relationships are possible when fines are added to a coarse sediment which originally has positive skewness (i.e., a shallow water sediment) or if fines are removed from a relatively poorly sorted sediment (i.e., a deeper water deposit). Either of these processes (Model I or Model II respectively) also explain the third relationship between skewness and sorting (Fig. 34C), which indicates that as sorting becomes poorer, skewness becomes less.

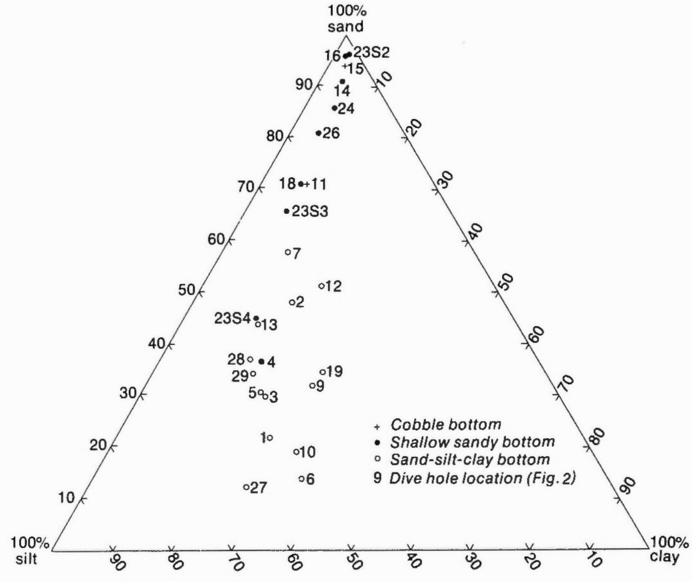


Figure 33. *Textural diagram of nearshore sediments.*

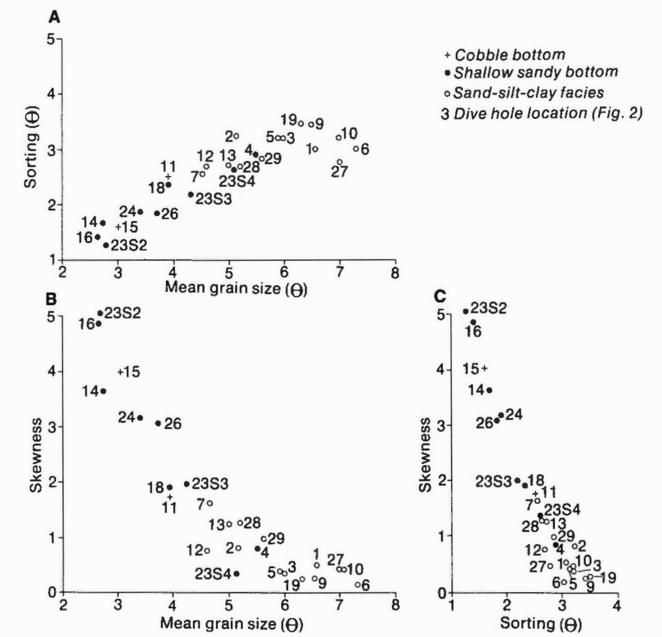


Figure 34. *Bivariate plots of textural parameters of Byam Channel sediments.*

Table 7. Matrix of correlation coefficients for nearshore grain size data, Byam Channel

		% Sand	% Silt	% Clay	Mean Grain Size	Sorting	Skewness	Depth
	Variable	1	2	3	4	5	6	7
% Sand	1	1.00	-.98	-.93	-.98	-.90	.93	-.71
% Silt	2		1.00	.84	.93	.86	-.91	.60
% Clay	3			1.00	.96	.88	-.87	.83
Mean Grain Size	4				1.00	.90	-.91	.73
Sorting	5					1.00	-.97	.71
Skewness	6						1.00	-.73
Depth	7							1.00

In summary, shallower water deposits are typically coarse grained, well sorted and positively skewed relative to deeper water deposits which are fine grained, poorly sorted and less skewed. The sediment changes linearly with depth and the relationships can be explained with either Model I or Model II. Model I is a depositional hypothesis and requires an onshore sediment source supplying a wide range of particle sizes. Model II is an erosional hypothesis requiring removal and redistribution of the fines. In the case of eastern Melville Island, the source sediment is believed to have been originally in deep water. During the Holocene, uplift brings the deposit progressively into the coastal zone allowing nearshore processes to modify the textural properties of the sediment.

Model II is favoured for the following reasons:

i. An analysis of sediment movement into Byam Channel indicates that little land-derived sedimentation is taking place on the sand-silt-clay facies. Sedimentation of clay and silt may be occurring beyond the 110 m isobath in bathymetric lows (McLaren, 1977).

ii. The lack of more than one sedimentary facies in the cores provides no indication of sedimentation.

iii. There is no relationship between radiocarbon dated shells and depth of burial.

iv. Diving observations support the hypothesis that little or no sedimentation is taking place (McLaren, 1977).

v. Diving observations suggest that mixing and redistribution of nearshore sediments by grounding ice and burrowing organisms are common and active processes.

Model II, therefore, suggests that the nearshore sediment, originally in deep water offshore, is probably a relict deposit (i.e. not a deposit reflecting present sedimentation). During isostatic uplift, this sediment is subject to increasing disturbance by grounding ice. Each time an ice block moves through the sediment and comes to a halt the following events are believed to occur: (i) New sediment is exposed in the scour track and its embankments thereby enabling currents to winnow surficial silt and clay. Perhaps a lag one grain thick rapidly forms on the newly exposed surfaces. (ii) Currents increase in the area surrounding the grounded ice block causing erosion of the terminal and lateral embankments. (iii) Burrowing organisms preferentially inhabit the softer sediment of an embankment thereby contributing to the suspension and removal of fines. (iv) The moving ice block itself may raise a flurry of sediment in its wake enabling fines to go into suspension. (v) After the scour track and embankments have reached stability, the foregoing cycle of disturbing processes will be reinitiated when a new ice scouring event buries and mixes the surficial lag deposit and exposes new sediment. (vi) Under ice tidal currents increase as depth decreases contributing to erosion and removal of exposed fines.

By the above processes the offshore sediment will become coarser and better sorted as depth decreases. It should be noted that all the fines are probably never completely removed from the original deposit. If they were, the result would ultimately be a negatively skewed grain-size distribution. The fines are preferentially winnowed away, possibly into deeper water, but portions of every size class interval found in the original deep-water deposit remain in the sediment. It is the removal of fines that result in the improvement in sorting and the development of a pronounced positive skew or tail in the direction of the fines in the shallow nearshore sediments.

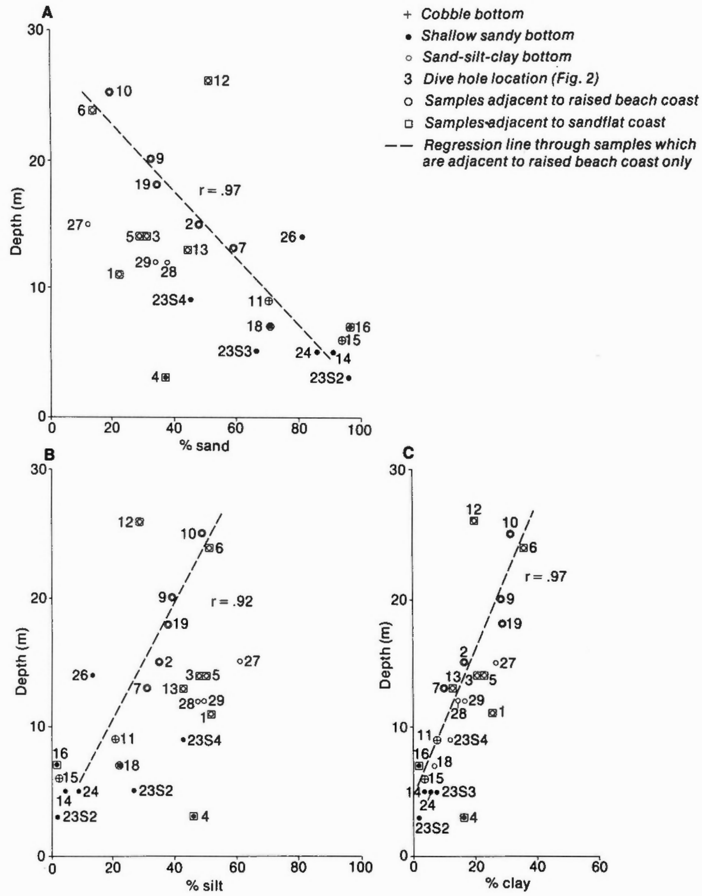


Figure 35. *Relationships of sediment texture with water depth.*

In spite of the good correlations between each variable and water depth (Table 7), there is an indication that the processes affecting the sediment have different magnitudes depending on the coastal type to which they are adjacent. A correlation matrix of variables taken from samples opposite a raised beach coast shows strong relationships between every variable and depth (Table 8; Fig. 35). However, if only samples adjacent to a sandflat coast are considered (Table 9; Fig. 35), it is seen that all correlations are essentially the same among the variables except with depth. In this case, the correlations are extremely poor (Fig. 35). The respective correlation coefficients are significantly different from each other at the 0.05 level.

This suggests that, although the general nature of the sediment is the same opposite both coastal types, ice scouring and currents which remove fines as depth decreases are more active and consistent in the channel bordering a raised beach coast than in the nearshore adjoining a sandflat coast. Perhaps winnowed fines from sediment opposite a raised beach coast are deposited in the nearshore of the sandflat coast resulting in a finer deposit (Fig. 35). Such a dilution combined with less frequent ice grounding would result in poorer grain size relationships with depth.

Table 8. Matrix of correlation coefficients for nearshore samples adjacent to the raised beach coastal type

		% Sand	% Silt	% Clay	Mean Grain Size	Sorting	Skewness	Depth
	Variable	1	2	3	4	5	6	7
% Sand	1	1.00	-.98	-.97	-.99	-.93	.93	-.97
% Silt	2		1.00	.89	.94	.91	-.94	.92
% Clay	3			1.00	.99	.90	-.86	.97
Mean Grain Size	4				1.00	.91	-.89	.98
Sorting	5					1.00	-.98	.85
Skewness	6						1.00	-.83
Depth	7							1.00

Table 9. Matrix of correlation coefficients for nearshore samples adjacent to the sandflat coastal type

		% Sand	% Silt	% Clay	Mean Grain Size	Sorting	Skewness	Depth
	Variable	1	2	3	4	5	6	7
% Sand	1	1.00	-.97	-.90	-.99	-.95	.95	-.32
% Silt	2		1.00	.78	.93	.96	-.93	.15
% Clay	3			1.00	.93	.79	-.84	.59
Mean Grain Size	4				1.00	.89	-.88	.33
Sorting	5					1.00	-.98	.28
Skewness	6						1.00	-.42
Depth	7							1.00

Origin of Nearshore Facies

Sand-silt-clay Facies

The foregoing discussion on the grain size analyses concluded that the sand-silt-clay facies is not the result of present deposition. If correct, the sediment must have originated during Holocene, Wisconsin or even pre-Wisconsin time. The textural nature of the facies is similar to a till, however it is hard to explain the presence of offshore till when it is absent onshore. It seems reasonable to suggest that this deposit is related to the last Wisconsin ice cover. If so, the pebbles and cobbles, which are almost entirely derived from local bedrock, imply an origin from either local ice caps covering Melville and Byam Martin islands or the Innuitian Ice Sheet (Blake, 1970; McLaren and Barnett, 1978) rather than from Laurentide Ice. Movement of Innuitian Ice from the northeast would have paralleled the bedrock strike on both Melville and Byam Martin islands resulting in the observed lithologies of the pebbles.

If not a till, the deposit perhaps originated as a glacial marine deposit during the breakup of the Innuitian Ice. On deglaciation and opening of the inter-island channels large amounts of ice must have melted and calved into the channels, resulting in a till-like deposit.

Swift et al. (1971) have used the term "palimpsest" in discussing Quaternary shelf sediments with petrographic attributes that reflect an earlier depositional environment, but which have been partially reworked during Holocene transgression. These authors note that such sediment, common along continental shelves and coastal inlets, represent an intermediate stage between unreworked true "relict" deposits and modern equilibrium deposits. The Byam Channel sediments fit, in part, this definition, the only difference being that the deposit may have originated in earliest Holocene rather than Pleistocene time.

Cobble Bottom

A cobble bottom is the result of either no original deposition of the sand-silt-clay facies or deposition that was sufficiently thin to have been removed by later processes. Either explanation demands higher energy levels than those acting on the sand-silt-clay facies. Diving observations indicated that cobble bottoms were all extensively ice scoured and on one occasion currents estimated at 50 cm/s were felt. The cobble bottom which extends offshore from rocky headlands receives the highest energy in terms of grounding ice and currents which tear up bedrock and winnow away fines respectively.

Shallow Sandy Facies

The shallow sandy facies encompasses three sedimentological environments; active delta fronts, inactive delta fronts and submarine extensions of the sandflat coastal type. The origin of the former has been discussed by Shearer (1974) in a study of uplifted delta deposits at Nelson Griffiths Point (Fig. 2). The similarity of the bedforms of the present delta plain to sedimentary structures observed in the uplifted delta section led Shearer to conclude that past depositional conditions were similar to those at present. For example, the active delta plain at Nelson Griffiths Point contains abundant linear and cuspate ripples as well as megaripples spaced 60 cm to 6 m from each other. The same bedforms were observed in cross-section in the uplifted delta plain deposits.

The raised prodelta deposits, which are probably analogous to the active delta fronts are composed primarily of fine sands and lesser amounts of silt and clay. Both parallel laminae and ripple-drift cross-lamination are present and indicate deposition by density flows down the delta front (Walker, 1969; Jopling and Walker, 1968). Shearer (1974) calculated that 30 to 40 kg/m^3 of suspended sediment would be required to produce the density difference between the inflowing river water and the salt water necessary for a density underflow. In a study on Consett Head River (Fig. 2), even the highest extrapolated value for suspended sediment was only 14 kg/m^3 (McLaren, 1977). Shearer concluded therefore, that the density underflow mechanism must be the result of bed load transport in the form of megaripples moving over the delta plain. These megaripples may deposit sediment at the edge of the delta plain where density underflows begin as a sudden mass movement down the delta front slope.

The rate of delta progradation has been approximated by Shearer (1974) to be 0.5 m/year. However, this value is a function of other processes as well since it was obtained by dividing the calculated age of a stratigraphic section in the uplifted portion of Nelson Griffiths delta by its distance from the present delta terminus. This distance is not only dependent on the progradation rate of the delta, but also on the original seafloor slope and its rate of uplift.

Two radiocarbon dates from separate laminae containing organic debris in an uplifted sequence of prodelta beds at Consett Head (Fig. 2) provide a better estimate of delta progradation (McLaren and Barnett, 1978). The distance normal to the beds was 7.47 m representing a horizontal distance of 20.40 m. The dates, 6630 ± 100 years B.P. and 5940 ± 150 years B.P. respectively yield an approximate horizontal growth rate of 2.95 cm/year with a possible maximum of 4.64 cm/year and a minimum of 2.17 cm/year.

The submarine extension of the sandflat probably owes its origin to longshore transport of sand from the delta fronts. This conclusion is based on (i) a dive observation that indicated that the shallow sandy facies was overlying the sand-silt-clay facies, (ii) the observation of migrating ripple marks moving parallel to shore under the influence of currents which are attributed to the partial constriction of the flooding tide under ice cover and (iii) grain size relationships of the respective beach faces (Table 10). If longshore transport is carrying sand from the delta fronts to the sandflat, it would be expected that the mean grain size on the beach face of a delta flat would be coarser than that on a sandflat. Similarly sorting should improve and skewness should become less with distance from the sediment source. Both mean grain size and skewness change as expected (Table 10), although sorting remains the same for both environments.

During transport from delta fronts to the sandflat coastline, there are many cases where the sand must encounter a raised beach coastline during its migration. Since energy levels are highest at these locations, it is probable that the sand bypasses them and continues moving to the quieter environments of the sandflat coastline. It is interesting that the mean grain size of the sand fraction in the beach face of the raised beach coastal type is the same as in the beach faces of the other two coastal types (Table 10). The sorting and skewness are significantly different at the 0.05 level which is due to the high gravel content of the raised beach coastline. The larger clasts of the raised beaches shield and retain fines thereby giving rise to a wider distribution of grain sizes than on the delta and sandflat beach faces.

Table 10. Moment measures (from Table 1) comparing the sediment of the beach faces of the three coastal types

Coastal type	Mean size	Mean sorting	Mean skewness
Delta beach face	2.6 ± .6Ø	1.5 ± .3Ø	3.9 ± 1.1Ø
Sandflat beach face	2.8 ± .3Ø	1.5 ± .3Ø	3.7 ± 1.3Ø
Raised beach, beach face	2.6 ± .5Ø	2.4 ± .6Ø	2.4 ± .6Ø

BEACH SEDIMENTOLOGY AND PROCESS MODELS

Introduction

In this study, samples were obtained from three coastal types, namely delta, sandflat and raised beach. These broad categories each contained several morphologic units (Table 1; Fig. 11, 12, 16) which were sampled as specific subenvironments. Combined with the nearshore environments, the complete sampling program encompassed a total of 14 morphologically and/or environmentally distinct units (Table 11). With the exception of the sand-silt-clay facies, a Q-mode factor analysis (Klovan, 1966) and a cluster analysis (J. Davis, 1973) failed to differentiate among environments. This lack of environmental differentiation may be caused by the following: (i) sediment transport is minimal and the grain size distribution reflects an omnipresent and homogeneous source material (i.e., local bedrock or Quaternary drift), (ii) transportation is occurring, but processes are sufficiently strong that essentially all size ranges are distributed along the coast, (iii) the sampling method and analyses have inadequately treated the gravel size and larger material which may be the most diagnostic component of the grain size curves. Elements of each of these three reasons are probably responsible for the similarity of the coastal sediments.

Failure to distinguish environmental differences by multivariate statistical techniques necessitated separate examination and comparison among each of the textural properties and the first three moment measures of the grain size distributions. The differences among these six grain size parameters combined with field observations provided, (i) a means of characterizing, and occasionally differentiating the subenvironments that each morphologic unit represents (ii) an indication of the types and relative magnitudes of processes acting on each of the coasts and their respective subenvironments and (iii) a prognosis of the origin of the coastal types.

Delta Coast

Sediment Characteristics of Morphologic Units

The delta coast is divided into an uplifted delta flat, a supratidal delta flat and a beach face (Table 11; Fig. 16). Analyses of these three morphologic units does not imply a total absence of other features. Berms and ridge and runnel systems are occasionally present on the beach, but insufficient grain size data exist to analyze them as separate morphologic units. The grain size parameters indicate the following:

i. Gravel size material is occasionally present in all three subenvironments (Table 1). Eighty-one per cent of all delta coast samples contained no gravel; in the remaining samples, the amount of gravel ranged from 4 to 16 per cent.

ii. The texture of the three subenvironments is predominantly sand and silty sand (Fig. 36). The beach face appears to have a higher percentage of sand when compared to the uplifted and supratidal delta flats; however there are no significant differences among the textural parameters. The sediment consists of a strongly positive skewed, poorly sorted, fine and very fine sand (Table 11).

Processes and Sediment Origin

The delta deposits are clearly derived from sediments eroded from within the drainage basins. The relatively small standard deviations of the delta grain size parameters (Table 11) attest to the widespread similarity of the source sediment. The largest proportion of the sediment is deposited as delta foreset beds which have been described previously as part of the shallow sandy facies. Insufficient data preclude separating delta foreset sands from the shallow sandy facies elsewhere. However, it is seen that the grain size parameters of the shallow sandy bottom have also relatively small standard deviations (Table 11) and it is therefore not unreasonable to consider the characteristics of the shallow sandy bottom as being essentially the same as the delta foreset deposits.

The beach face of the delta environment undergoes seasonal wave activity and occasional modification by ice push. The latter, which undoubtedly occurs, is not considered important because, (i) the break in slope between topset and foreset beds which occurs in approximately 3 m of water opposite the river mouths is a natural place for ice to ground and does not affect the beach face and, (ii) the only material available to be added to the beach by ice push is sand from the shallow sandy facies which will be redistributed by waves leaving no trace of the ice push.

The shallow sandy facies is modified at the beach face by wave activity. This results in a slightly coarser, better sorted sediment somewhat depleted in fines (silt and clay) and with a greater positive skewness (Table 11). The greater skewness is caused by some, but not all of the fines being removed. Parts of each size class found in the shallow sandy facies are still present in the beach face.

Sedimentation on the supratidal delta flat occurs only during high wave activity or extreme tides. The high energy extreme event enables the sediment of the shallow sandy facies to be deposited with little significant change in the grain size characteristics. The supratidal deposits, therefore, contain some fines and are less skewed than the beach face and are almost identical to the nearshore sandy facies (Table 11).

The supratidal delta flat, once removed from littoral processes, becomes the uplifted delta flat. Subaerial exposure allows some deflation and sheet runoff to occur periodically. These processes may explain the decrease in the clay fraction of the uplifted delta flat resulting in better sorting and a slightly higher skewness when compared to the supratidal deposits.

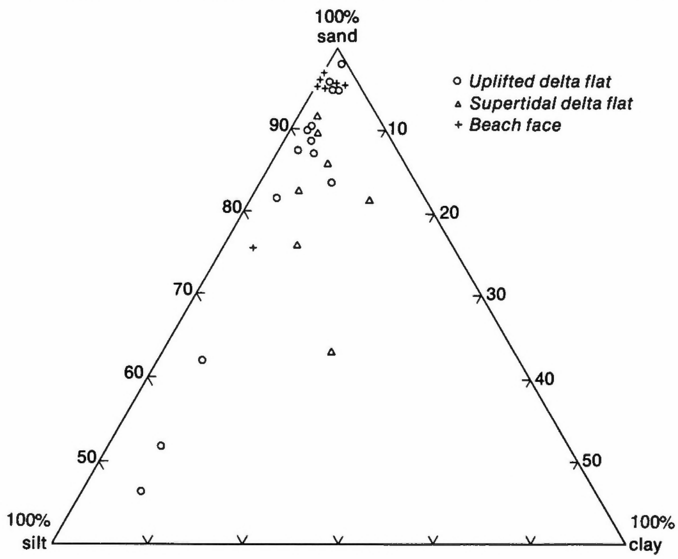


Figure 36. *Textural diagram of delta coast sediments.*

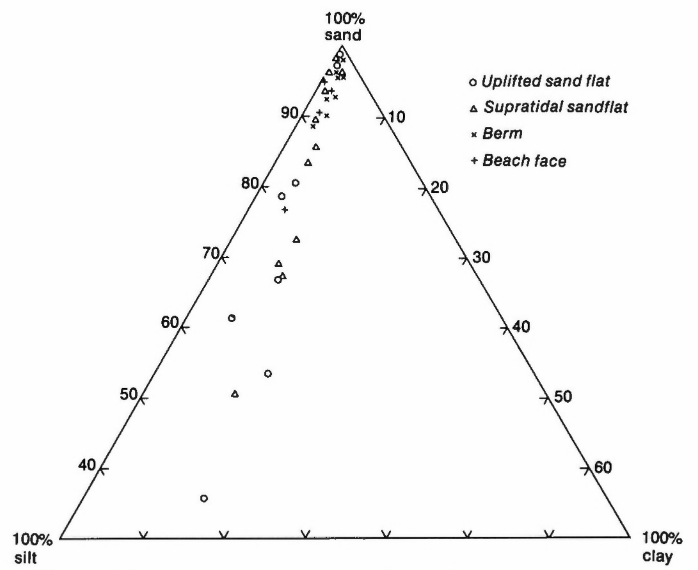


Figure 37. *Textural diagram of sandflat coastal sediments.*

Table 11. Summary of sediment characteristics for coastal sub-environments (from Table 1 and 10)

		Texture			Moment Measures (>1Ø)			
Coastal Type	Morphologic Unit	Mean % Sand	Mean % Silt	Mean % Clay	Mean Size	Mean Sorting	Mean Skewness	No. of Samples
Sandflat	Uplifted sandflat	71 ± 22	22 ± 16	7 ± 6	3.86 ± 1.03	2.06 ± .05	2.23 ± 1.75	8
	Supratidal flat	82 ± 16	14 ± 12	5 ± 4	3.37 ± .73	1.82 ± .77	2.94 ± 1.58	11
	Berm	94 ± 3	4 ± 3	2 ± 1	2.67 ± .23	1.37 ± .27	4.49 ± .93	9
	Beach face	91 ± 8	8 ± 7	2 ± 2	2.75 ± .33	1.53 ± .33	3.71 ± 1.27	5
Raised beach	Raised beach top	80 ± 10	15 ± 8	5 ± 3	2.78 ± .71	2.46 ± .61	1.90 ± 1.03	9
	Raised beach face	77 ± 10	17 ± 7	6 ± 3	3.03 ± .72	2.60 ± .60	1.76 ± .96	9
	Interbeach lagoon	80 ± 11	15 ± 8	5 ± 3	3.45 ± .50	2.15 ± .44	2.45 ± .99	13
	Berm	83 ± 9	13 ± 7	4 ± 2	2.65 ± .75	2.40 ± .48	1.88 ± .75	9
	Beach face	85 ± 6	12 ± 5	4 ± 2	2.60 ± .47	2.35 ± .58	2.05 ± .85	9
Delta	Uplifted delta flat	84 ± 15	13 ± 14	3 ± 2	2.23 ± .58	1.62 ± .38	3.63 ± 1.26	12
	Supratidal delta flat	82 ± 10	12 ± 5	6 ± 5	3.36 ± .59	2.18 ± .59	2.69 ± 1.24	8
	Beach face	93 ± 8	6 ± 7	2 ± 2	2.60 ± .59	1.53 ± .32	3.89 ± 1.09	6
Shallow sandy bottom		79 ± 18	15 ± 14	6 ± 4	3.59 ± .87	1.91 ± .46	3.14 ± 1.36	9
Sand-silt-clay bottom		33 ± 14	45 ± 9	22 ± 7	5.92 ± .92	3.02 ± .30	0.69 ± .45	14

Sandflat Coast

Sediment Characteristics of Morphologic Units

The morphologic units of the sandflat coast are identical to those of the delta coast with only the addition of a berm feature. Examination of the grain size characteristics (Table 11) indicate the following:

i. Gravel size material, not significantly different from that found in the delta sediments occurs in small quantities in the uplifted and supratidal sandflats. Thirty-seven per cent of samples from these two morphologic units contained from three to six per cent gravel. No gravel was observed in either the berm or beach face.

ii. The subenvironments consist predominantly of sand and silty sand (Fig. 37). Only the berm is entirely sand (i.e., greater than 80% sand). There are no significant differences in the textural parameters between the beach face, supratidal and uplifted sandflat. The berm, however, contains significantly less silt and clay (Table 11). Similar to the delta sands, the sandflat subenvironments consist of a strongly positive skewed, poorly sorted, fine and very fine sand (Table 11).

Processes and Sediment Origin

The shallow sandy facies, as previously discussed, slopes seaward from the sandflat coast to a depth of approximately 7 m. It was suggested that the shallow sandy bottom is derived from the longshore transport of delta sands and overlies the sand-silt-clay facies found beyond the 7 m isobath (Fig. 38). Grain size relationships with depth indicated that ice scouring activity adjacent to sandflat coasts is less than elsewhere. Nevertheless, this does not mean ice scouring and ice push never occur on a sandflat.

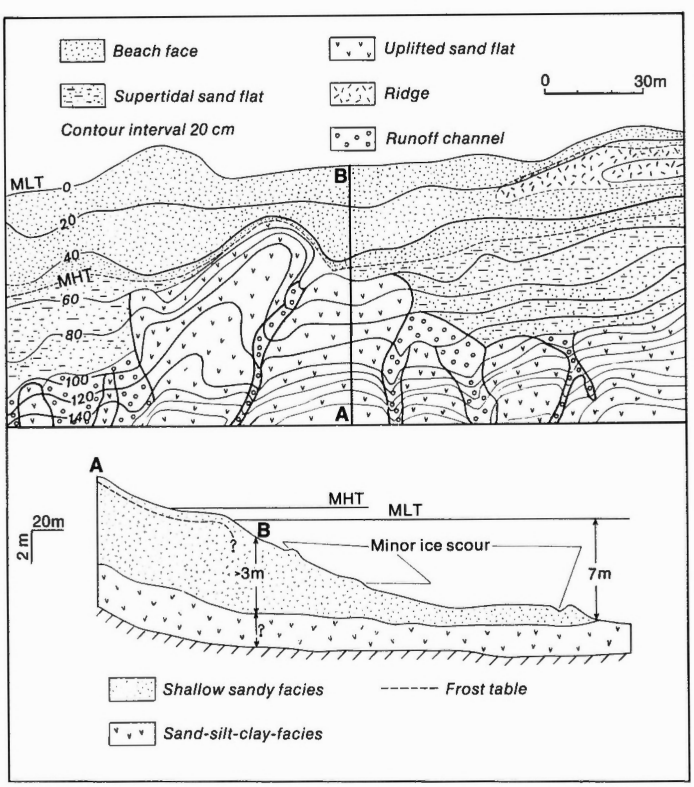


Figure 38. *Zonal model (Z_4, Fig. 2) of a sandflat coast.*

The absence of beach gravels suggests that ice push is not capable of scouring through the shallow sandy facies to the sand-silt-clay facies which would result in gravel being added to the beach. Ice scouring was seldom observed to be greater than 3 m which implies that 3 m may be a minimum thickness for the shallow sandy sediment (Fig. 38). Therefore, like the delta environment, the shallow sandy facies acts as a buffer against ice push and inhibits sediment other than sand being added to the beach.

Modification at the shoreline of the shallow sandy facies by wave action is reflected in the grain size parameters (Table 11). The beach face, which undergoes continuous minor wave activity during the open water season, contains less silt and clay, is somewhat better sorted and is more positively skewed than the shallow sandy facies. The berm, when present, is formed in a slightly higher energy regime which results in an even coarser, better sorted sediment than found on the beach face (Table 11). Wave energies capable of inundating the supratidal area are also capable of transporting all size fractions of the shallow sandy facies. The result is a sediment more similar to the shallow sandy facies than either the beach face or the berm (Table 11). The uplifted sandflat is not significantly different from either the supratidal or the shallow sandy facies.

Raised Beach Coast

Sediment Characteristics of Morphologic Units

The presence of gravel size and larger clasts in all the morphologic units of the raised beach coast differentiates this coastal type from the others. The mean gravel content ranges from 49 ± 31% in the beach face to 8 ± 8% in the interbeach lagoons (Table 1), which is significantly higher than in any other subenvironment. The following observations apply to the textural components of the raised beach coast sediments:

i. The ice push boulder barricade, which forms the seaward most morphologic unit where the raised beaches are perched on rock, consists predominantly of boulders, with little or no fine material (Fig. 39). The lithology of the boulders invariably reflects the underlying bedrock. Characteristically, the clasts are angular and show little sign of weathering.

ii. The boulder and cobble pavement, also found only where raised beaches are perched on rock, is identical to the boulder and cobble bottom found adjacent to the rocky headlands in the nearshore. The clast size is generally smaller than the boulder barricade and consists predominantly of gravel and cobbles. The sharp angularity of the cobbles indicates little mechanical weathering.

iii. The present beach face of the raised beach coastal type contains a highly variable gravel content that ranges from 94% to 11% (Fig. 40). A higher gravel content is found on the beaches that are overlying rock as opposed to those overlying sand. The former contain pebbles unique to the local bedrock, whereas beaches that are perched on sand can contain a number of lithologies including granite erratics. Many of the clasts show evidence of abrasion, being often subangular to subrounded. Frost shattering, however, tends to fracture other clasts into flat, angular rock fragments.

iv. The berm top is characterized by a more consistent percentage of gravel than the beach face (Fig. 40). It ranges from 41% to 72% gravel. Like the beach face, lithology is dependent on the closeness of bedrock to the surface; only one rock type is observed if the beach overlies rock.

Figure 39. *Ice push boulder barricade at Z_3 (Fig. 2). GSC 203123-C*

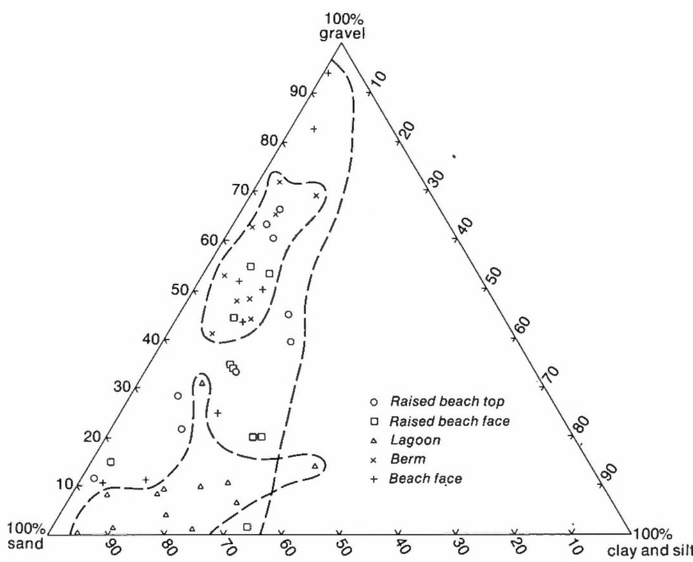


Figure 40. *Textural diagram of raised beach coastal sediments.*

Figure 41. *Minor ice push event at Z_2. GSC 202953-G*

Figure 42. *Fresh bedrock deposited on Beach at Z_2 by ice push shown in Figure 41. GSC 203123-G*

v. The lagoon contains least gravel (8 ± 8%) and is texturally distinct from the other subenvironments (Fig. 40).

vi. The percentage of gravel in the raised beach face and raised beach top is not significantly different from that found in the present beach face and berm (Table 1; Fig. 40). The gravel is however, somewhat finer which is due to frost action which tends to break apart the clasts. This produces a slightly more angular gravel.

vii. A separate examination of the sand size and smaller sediment indicates that the textural properties of the subenvironments are essentially the same. The amount of sand ranges from 77 ± 10% to 85 ± 6% and is predominantly very poorly sorted, positively skewed, fine and very fine sand (Table 11).

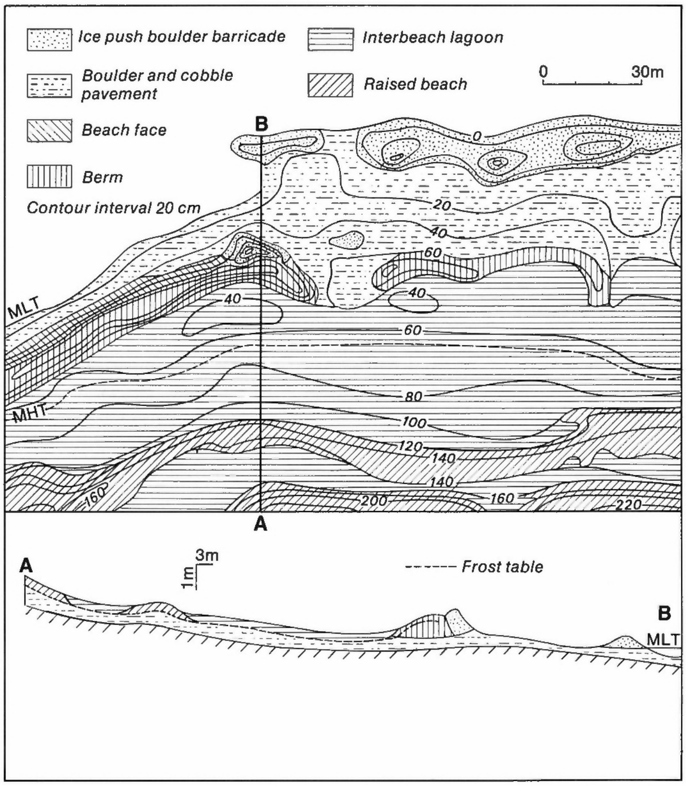


Figure 43. *Zonal model (Z_3, Fig. 2) of raised beach coast; beaches perched on rock.*

Processes and Sediment Origin

The net effect of ice scouring in the nearshore is to move material towards shore. In the process, fines tend to be winnowed, resulting in a negative relationship between grain size and water depth. It was discussed earlier that this correlation was most pronounced in the areas adjacent to the raised beach coastal type and appears to be least prevalent in the nearshore opposite a sandflat coast. Even when scouring does occur on the sandflat and delta coasts, the mantle of sand that the shallow sandy sediment provides inhibits the sand-silt-clay facies (which contains gravel) from being pushed onto the beach.

The shallow sandy facies is completely absent at the rocky headlands where the raised beaches are perched on rock; probably, it is thin and discontinuous adjacent to the rest of the raised beach coastline. The result is that either boulders and cobbles torn up by ice scouring, or the sand-silt-clay facies can be added to the beach by ice push (Fig. 39, 41 and 42). The gravel content of the sand-silt-clay facies is concentrated at the beach by further winnowing of fines.

The nature of the raised beach coast is therefore, dependent on the nearshore bottom type. If there is no sand-silt-clay facies, such as opposite rocky headlands, ice scour on the cobble bottom initially forms ice push boulder barricades (Fig. 39, 43). The boulder barricade is made up of boulders and cobbles from the existing pavement as well as fragments of newly torn-up bedrock.

As emergence occurs, ice action, frost shattering and wave processes tend to break apart the large clasts into the gravel size material which constitutes the beach. Between the boulder barricade and the present beach (Fig. 43), the boulder and cobble pavement forms an early prototype interbeach lagoon (Fig. 44). The present beach, which probably originated as a boulder barricade, lies seaward of an interbeach lagoon both of which are in the process of emerging to become part of the uplifted raised beach complex. In this way, the combination of ice push and coastal emergence forms a raised beach coastline.

Where raised beaches are not resting on bedrock or the boulder and cobble pavement, the situation is more complex. It was suggested earlier that the shallow sandy facies, possibly in transit to the sandflat coastal type, is thin and perhaps discontinuous in such areas. There is not a sufficient thickness of sand to protect the beach from addition of gravel originally in the sand-silt-clay facies. If the shallow sandy facies is present, it is suggested that it is less than 3 m

A: Ice push boulder barricade;

B: Boulder and cobble pavement forming an early, prototype interbeach lagoon;

C: Present beach;

D: Interbeach lagoon;

E: Raised beach.

Figure 44. *Aerial view of Z_3. Area enclosed is mapped on Figure 43. GSC 203123-I*

thick which would enable ice scour to gouge into the underlying sand-silt-clay facies (Fig. 45). Thus ice push can provide the material for gravel beaches to form, but they may be overlying a sand which is, in fact, the shallow sandy facies. It was observed occasionally that fresh bedrock fragments were also present in the ice push deposits (Fig. 42), in which case the combined thickness of the shallow sandy and sand-silt-clay facies may be sometimes less than 3 m.

Ice push deposits may be added directly onto the present beach face where waves quickly distribute the gravel and winnow the fines or they may be on top of the berm (Fig. 45, 46). When storms occur, erosion of the beach face results in these ice push deposits being incorporated into new beach material (Fig. 47). The interbeach lagoon, behind the present beach, is a subaerial continuation of the thin, shallow, sandy facies. This is confirmed by the fact that the grain size parameters of the interbeach lagoon sediments are essentially identical to the shallow sandy facies (Table 11).

The raised beach coastline therefore, owes its origin to ice push deposits which are superimposed onto the movement of the shallow sandy facies about the coastline. An examination of the sand size material shows that the beach face contains slightly more sand and is significantly coarser than the shallow sandy facies (Table 11). It also is more poorly sorted and has less of a positive skew. These relationships are probably due to the breakdown of the gravel into large sand size particles and the protection of the fines by the presence of the large clasts.

There are no significant differences between the raised beach top, raised beach face and berm (Table 11). The lagoon, however, contains significantly finer sediment than the other subenvironments, being more similar to the original shallow sandy facies.

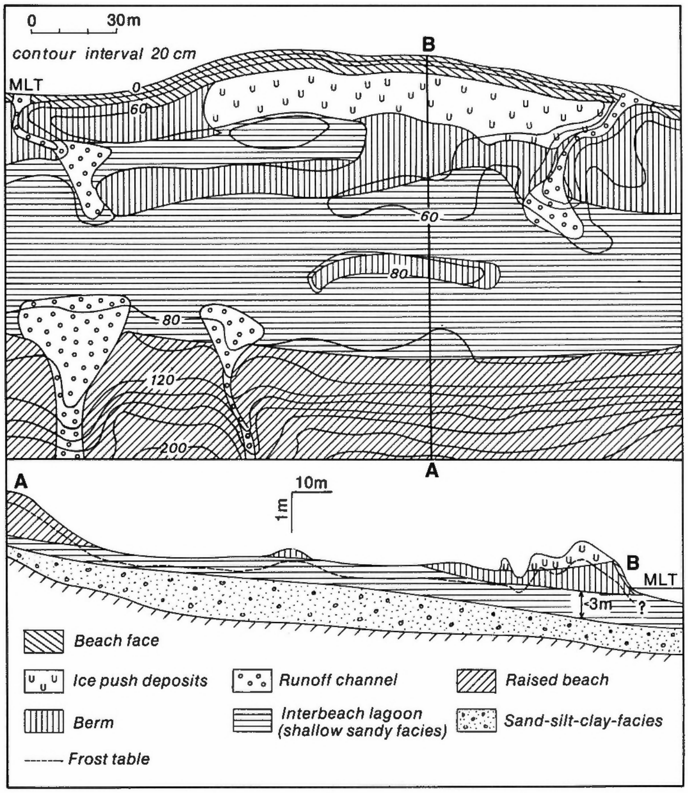


Figure 45. *Zonal model (Z_1, Fig. 2) of a raised beach coast; beaches perched on sand.*

Summary Model

The coasts of eastern Melville and western Byam Martin islands owe their origin to uplift during the Holocene and are therefore dependent, to some extent, on the nature of the nearshore bottom. Superimposed on the emergence are two important processes: (i) the deposition of sand at delta fronts and its transport in the nearshore between the shoreline and the 7 m isobath; and (ii) the effects of ice push which transport gravel and larger clasts to the beach. The latter occurs where the shallow sandy facies is thin or absent allowing ice to scour into the sand-silt-clay facies or bedrock.

The sand originates at the deltas and is transported laterally as the shallow sandy facies to the sandflat coast (Fig. 48). It would be expected, therefore, that the overall characteristics of the sandflat sands would be finer, better sorted and less skewed than the sands of the delta. Although these trends do occur (Table 12) none of the differences are significant at the 95% level suggesting that longshore transport processes are sufficiently strong to carry all size ranges of the delta sands.

Figure 46

Ice push deposit at Z_1 (Fig. 45) overlying a berm. An interbeach lagoon is in the background. GSC 203123-L

Table 12. Summary of sediment characteristics from all samples for each coastal environment

Environment	Texture: Mean % Sand	Texture: Mean % Silt	Texture: Mean % Clay	Moment Measures (>-1∅): Mean Size	Moment Measures (>-1∅): Mean Sorting	Moment Measures (>-1∅): Mean Skewness	No. of Samples
Sandflat Coast	84 ± 17	12 ± 12	4 ± 5	3.21 ± .81	1.71 ± .70	3.30 ± 1.62	33
Raised Beach Coast	81 ± 9	14 ± 7	5 ± 3	2.97 ± .71	2.37 ± .54	1.88 ± .93	49
Delta Coast	85 ± 13	11 ± 11	4 ± 3	3.13 ± .64	1.77 ± .56	3.40 ± 1.27	26
Shallow Sandy Bottom	79 ± 18	15 ± 14	6 ± 4	3.59 ± .87	1.91 ± .46	3.14 ± 1.36	9
Sand-Silt-Clay Bottom	33 ± 14	45 ± 9	22 ± 7	5.92 ± .92	3.02 ± .30	0.69 ± .45	14

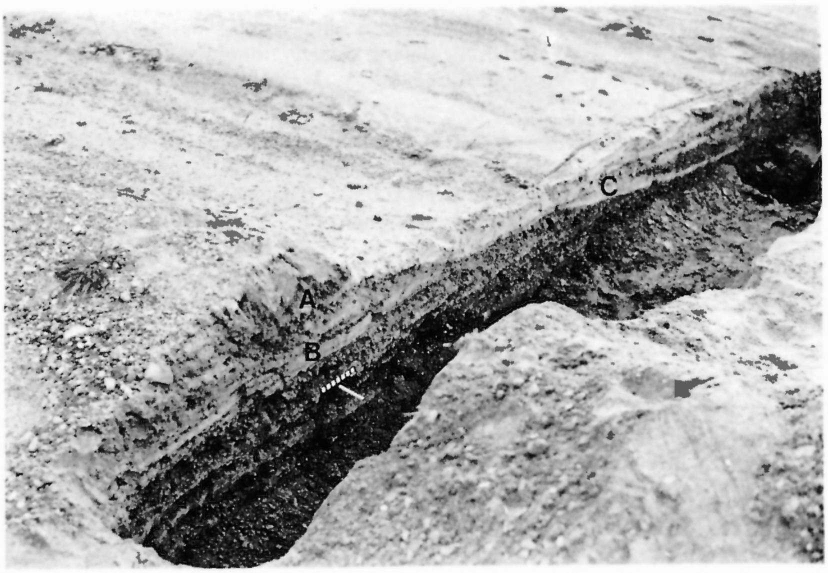


Figure 47

Trench at Z_1 showing ice push deposit (A) overriding horizontal berm deposits (B) which have been truncated by the present beach face (C). The last storm has incorporated some of the ice push deposit into the beach sediment. Scale is 15 cm. GSC 203123-M

In transit from delta to sandflat, the sand must pass the raised beach coastline. The presence of large clasts and possibly the addition of fines from the sand-silt-clay facies by ice push cause the sand to be significantly more poorly sorted and less skewed than either the delta or the sandflat sediments (Table 12). The shallow sandy facies is characteristically finer than the beach sediments which have undergone sorting by wave action (Table 12).

The sand-silt-clay facies is significantly different from all the other environments, being finer, more poorly sorted and less skewed (Table 12). The grain size relationships with depth indicate that ice scouring and currents are strongest opposite the raised beach coastline (Fig. 48). This results in the shallow sandy facies being thin and allows ice push to add gravel to the beach. It is the presence of gravel that maintains a beach form after emergence has occurred resulting in a raised beach coast.

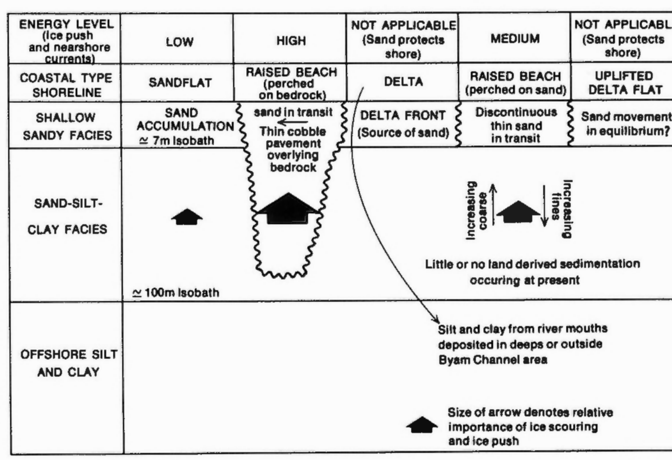


Figure 48. *Diagrammatic summary model of the Melville and Byam Martin islands coasts.*

CONCLUSIONS

Deglaciation of Byam Channel occurred at least 10 200 years ago with the breakup of either the Innuitian Ice Sheet or local Melville Island ice caps or both (McLaren and Barnett, 1978). It is speculated that during deglaciation much ice was rapidly removed by the calving of glacier fronts into the increasingly open inter-island channel system, notably through Byam and Parry channels. Release of glacial debris by melting ice deposited at least 6 m of glaciomarine sediment (McLaren et al., 1975) in Byam Channel which is characterized by a mixture of sand (33%), silt (45%) and clay (22%) as well as varying amounts of pebbles and cobbles of local bedrock origin. In some areas of the channel, probably topographic highs, this sand-silt-clay facies is now absent indicating that currents at the time of deglaciation were too strong to allow deposition, or the sand-silt-clay facies has since been eroded away leaving a cobble pavement overlying bedrock.

Since deglaciation, the coasts have emerged approximately 100 m and they appear to be still undergoing isostatic recovery at a rate of approximately 0.35 cm/year (McLaren and Barnett, 1978). During the Holocene, drainage into Byam Channel has resulted in the growth of Gilbert deltas consisting predominantly of sand which prograded during emergence. Sand from the delta fronts is transported by currents over the sand-silt-clay facies adjacent to the coastline. Transport probably occurs in winter by under-ice tidal currents which are augmented in the shallow water. The sand, in transit, comes to rest in those parts of the coast where energy levels are too low for further transport. This shallow sandy facies extends from the shoreline to the 7 m isobath approximately. Beyond the shallow sandy facies little or no sedimentation is occurring except in bathymetric lows probably deeper than 100 m.

The present coastal types are dependent on emergence, the nature of the nearshore materials and the amount of ice action on the shoreline. Where the sand-silt-clay facies is absent energy levels in terms of ice scouring and currents are highest. The shallow sandy facies cannot remain in a high energy environment. Ice push enables boulders and cobbles of bedrock material to be deposited near the shoreline in the form of an ice push boulder barricade. As emergence occurs the barricade, acted on by waves, frost action and probably further ice push, becomes the present beach. Continued emergence produces a raised beach, consisting predominantly of gravel, which is perched on a cobble pavement.

On other parts of the coast, the sand-silt-clay facies is present and ice push can deposit the facies, including gravel and larger material onto the beach. Wave action winnows the fines, leaving a gravel beach which again, is able to maintain its geomorphic form after emergence is complete. Occasionally the shallow sandy facies may be present. If it is thin (<3 m), ice can scour deeply enough to reach either the sand-silt-clay facies or bedrock, still enabling gravel beaches to form. These beaches may be perched on sand which is the emerged shallow sandy facies.

Where the shallow sandy facies is thick (>3 m), ice is incapable of scouring deeply enough to bring gravel to the beach. Thus only sand can be added to the beach by ice push. Without a gravel component, the beach does not maintain its morphologic form after emergence. The shallow sandy facies, when uplifted, becomes the sandflat coastal type.

Grain size analyses and field observations indicate that, (i) coastlines consisting of raised beaches perched on rock receive the highest energy with respect to currents and ice push, (ii) where raised beaches are perched on sand, energy levels are intermediate, (iii) sandflat coasts receive the lowest amounts of energy, (iv) nearshore currents are capable of transporting all size fractions of sand found on the delta fronts to the sandflat coast, (v) longshore transport cannot move gravel and larger sized material any significant distance, hence raised beaches are confined to those areas where gravel has been added to the beach by ice push.

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